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Comparisons of Grafted Biennial and Conventional Production Systems for Eggplant (*Solanum melongena* L.) Varieties in a Mediterranean Region of Turkey

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Abstract: Annual conventional production of eggplant and biennial growing by using grafted seedlings were compared over a two-year period in the Mediterranean Amik plain of southern Turkey. Grafted (onto *Solanum torvum* Swartz.) and nongrafted control seedlings of eggplant (*Solanum melongena* L.) cultivars Pala and Faselis F_1 were transplanted to the soil free of important soil-borne pathogens, *Verticillium*, *Fusarium* and nematodes. Grafted plants were grown for the period 2002-2003 by pruning at the end of the first year. Control plants were grown as in conventional eggplant production by planting fresh seedling every year. The effects of grafting on fruit yield, quality and plant growth differed depending on cultivars. The mean fruit yield, quality and plant growth of Faselis decreased due to grafting in the second production year, while only fruit quality was reduced in the first year. However, the mean fruit yield of both grafted and control plants of Pala were similar and growth was more vigorous in grafted plants than the control ones of this in the two years. The effect of grafting on the fruit quality of Pala was not clear as the fruit quality differed depending on cropping year. Present results suggested conclusion, the production of eggplant grown from the same grafted plants in all the years could be used for Pala, but Faselis. It is possible to suggest that biennial eggplant growing by using grafted seedlings is more profitable and ecologically sustainable than conventional ones.

Key words: *Solanum torvum*, fruit quality, growth, yield

INTRODUCTION

Eggplant is of great economic importance in Turkey which is the third largest producing country after China and India, with 970,000 tons of eggplant produced annually[1]. Protected cultivation of eggplant accounts for 20% of total eggplant production in Turkey. Commercial production of eggplant is limited by soil-borne diseases; however, grafting is not yet popular even in protected cultivation.

Usage of grafted seedlings in commercial production of vegetables did not become popular until the 1960s, although the benefits of using grafted seedlings were first published in the late 1920s[2]. The introduction and active use of plastic films in horticulture triggered the increase in protected cultivation in temperate Asian countries and improved grafting technology in vegetable production. Usage of grafted seedlings in protected vegetable cultivation increased because of the stressful conditions in the plastic greenhouse and high tunnels. These conditions cause various physiological as well as pathological disorders, thus leading to severe losses of crop yield[2]. Nowadays, vegetable production by grafted seedlings has become a common practice, especially for the cultivation of cucumber, melon, watermelon, tomato, pepper and eggplant in greenhouses or plastic houses in Japan, Korea, China and some Asian and European countries[2,3]. Introduction of excellent rootstocks with multiple disease resistance and efficient grafting machines including grafting robots are most likely to encourage the extended use of grafted vegetables worldwide[2,4]. We believe that grafted vegetable seedlings can be used intensively in the protected cultivation in Turkey in the near future, if the cost of grafted seedlings is considerably reduced.

Eggplant is susceptible to numerous diseases and parasites, particularly bacterial wilt, *Fusarium* and *Verticillium* wilts, nematodes and insects[5]. Soil-borne pathogens and pest such as *Verticillium*, *Fusarium* and *Meloidogyne* spp. may cause yield losses, up to 78% in production areas infested with *Verticillium* wilt[6]. The continuous use of the same field for the cultivation of eggplant or other hosts susceptible to a number of pathogens leads to an increase in the soil inoculum. In addition, the difficulties in chemical control of the diseases, the absence of crop rotation and sexual barriers

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between eggplant and its wild relatives indicated that the only short term practical solution to the problem is the growing of the susceptible eggplant cultivars grafted on rootstocks with multiple disease resistance[5,6]. The percentage of cultivated area of grafted eggplant seedlings on rootstocks in Japan increased to 43% in open field and tunnel and to 94% in greenhouse[2].

The most common rootstocks of eggplant are wild related species such as *Solanum torvum* Swartz, *Solanum integrifolium* Poir. and *Solanum sisymbriifolium* Lam.[3,6]. *S. integrifolium* exhibits resistances to *Fusarium* and bacterial wilts, spider mite and mycoplasma[7]. *S. torvum* was reported to be resistant to *Verticillium* and bacterial wilt, root knot nematode and mycoplasma[5,7]. Susceptible eggplants were grafted on rootstock of *S. integrifolium* early in 1950s with satisfactory results[6]. Oda *et al.*[4] showed that eggplant plugs grafted on *S. integrifolium* with the newly developed robot can be safely used for production of grafted transplants on a commercial scale, since grafted plants by robot produced similar fruit yields as did plants grafted by hand. Suzuki and Morishita[8] reported that *S. torvum* was more vigorous rootstock than *S. integrifolum*, as the graft combination of a vigorous scion on an equally vigorous rootstock *S. torvum* reduced the amount of fertilizer required. Bletsos *et al.*[6] found that grafting of eggplant onto *S. torvum* and *S. sisymbriifolium* had positive effects on plant growth, production and disease incidence of *Verticillium dahliae* Kleb. with no change in fruit quality and that *S. torvum* was more resistant than *S. sisymbriifolium* to the *Verticillium* wilt. Grafting is time consuming, labour-intensive and requires more space and materials[6]. However, there is no report on the effectiveness of grafted eggplant when grown biennially to reduce the extra cost of grafted seedlings even by robotic grafting method.

Using grafted material increases the inputs of the annual conventional eggplant production. However, if they are grown biennially, the higher cost of the grafting might be compensated by the fewer seeds used. Such a biennial system can be advantageous from a sustainability of the production as well. These advantageous are expected to be greater in the areas infected by diseases. Therefore, we designed a study to assess the production of grafted eggplant varieties (on *S. torvum*) grown biennially and conventional nongrafted ones, by determining plant growth, yield and fruit quality over two successive years.

MATERIALS AND METHODS

The experiments were carried out at Agricultural Research Station of Mustafa Kemal University, Antakya in southeastern Mediterranean region of Turkey under irrigated conditions in 2002 and 2003. The study area is in Amik plain that lies near latitude 36°19′N and longitude 36°11′E, with an attitudinal range of 100 meters above sea level. Prevalent climate of the study area is characterized by Mediterranean climate (sub-tropical) under which about 70% of annual rainfall of 1,124 mm falls in the winter. The mean annual temperature is 18°C with a maximum of 44°C in the summer and a minimum of -15°C in the winter. Some climatic data of the study area are presented in Table 1.

Preliminary and the first experiments were conducted in a field in 2001 and 2002, respectively and the second experiment was conducted in a glasshouse in 2003. Only the results of the first and second experiments will be presented. In the experiment plots, *Solanum* species had not been grown for at least five years. The experimental design consisted of a Randomized Complete Block Factorial Design with three replicates per treatment. The cultivars as well as the treatments were assigned to the plots at random. This investigation was focused on yield, fruit quality and growth responses of eggplant to a two-factor factorial trail with cultivars (Pala and Faselis F_1) and grafting (grafted on *S. torvum* and not grafted). Mixture of composted sheep-cattle manure of 4 and 12 kg m^{-2} was applied in outdoor and in glasshouse cultivation, respectively one month before planting. The total amounts of N-P_2O_5- K_2O applied to the plots in outdoor and in glasshouse were 49-13-78 and 70-18-112 g m^{-2}, respectively[9]. All the manure and fertilizer applications were immediately incorporated into soil.

Seeds of eggplant cultivars Faselis F_1 (from De Ruiter Seeds, Holland) and Pala (from Atatürk Central Horticultural Research Institute, Turkey) were sown in peat materials on 18 January and 12 November in 2002. Cuttings of *S. torvum* with two buds were rooted in

Table 1: Monthly climatic data of the study area for the period of the experiments

Year	Month	Average temperature (°C) Max.	Min.	Mean	Relative humidity (%)	Wind speed ($m\ s^{-1}$)	Preci-pitation (mm)
2002	January	11.8	3.3	7.0	74.5	1.6	204.0
	February	18.0	7.5	12.4	68.3	1.8	92.9
	March	19.9	9.7	14.2	67.9	1.8	163.8
	April	20.8	13.2	16.6	73.3	2.6	234.2
	May	25.8	16.8	21.1	67.6	3.2	11.6
	June	30.3	21.3	25.5	63.4	3.8	9.0
	July	32.4	25.1	28.2	66.2	4.3	0.0
	August	31.9	25.0	27.8	67.4	4.2	15.2
	September	31.1	21.7	25.6	65.7	2.9	27.5
	October	28.9	16.4	22.0	62.4	1.5	30.4
	December	22.8	10.7	15.6	67.7	1.3	69.2
	November	12.3	4.6	7.8	70.2	1.6	148.3
2003	January	14.1	6.7	9.9	79.0	1.5	153.8
	February	11.5	4.4	7.4	77.6	1.8	272.1
	March	16.1	7.3	11.2	71.2	1.8	233.9
	April	21.8	13.0	16.8	71.4	2.4	45.4
	May	30.6	17.7	23.7	54.8	2.5	46.8
	June	29.7	21.8	25.4	67.5	4.0	10.8
	July	31.7	24.7	27.7	69.8	4.6	18.9
	August	32.7	25.9	28.6	70.2	4.6	0.0

Source: Weather Station of Antakya, 2002-2003 growth medium made of 1 peat: 1 perlite materials at the end of January in 2002. On the second week of April, the eggplant cultivars were grafted onto rooted cuttings of *S. torvum* by budding method and placed under low plastic tunnels (80 cm wide x 60 cm high) in glasshouse. Nongrafted control and grafted plants once reaching planting height (plants with 8-10 leaves) were transplanted to the outdoor field on 1 June at a density of 0.75x0.6 m (between rows x on rows). At the end of the season, 31 October, only grafted plants were pruned and transferred to the unheated glasshouse. After two months, control seedlings were planted to the soil in the greenhouse by spacing of 0.6x0.6 m (between rows x on rows). Grafted and control seedlings had similar leaf number at this stage. Four stems were trained on each plant. The plants were irrigated with drip irrigation on plots of 4.5 m^2 (0.75x6 m) and 1.8 m^2 (3x0.6 m) with 10 and 5 plants per each plot in outdoor and glasshouse, respectively. Unless otherwise noted, measurements were made on 8 plants in outdoor and on 3 plants in glasshouse, by excluding the first and last plants within rows.

Fruit yields of the vegetables were taken from each plot and weighted on a weekly basis during July and October in outdoor and during March and August in glasshouse. Weights from each plot for each week were tallied, analyzed and presented as average total per plant in kg. The following response variables were measured at least three times during the harvesting period: fruit weight (g), fruit length (cm), fruit width (mm), total soluble solid (°Brix), oxalic acid (%) and pH. Measurement of pH was made in the fruit juice using a digital pH meter (HANNA instruments 8521) and total soluble solids were measured in a few drops of the fruit juice using a hand refractometer (NOW model No. 507-I). Leaf area (cm^2), plant length (cm), main stem diameter 1 cm above the graft union (mm) and biomass (g) were recorded at the end of the cropping years. From each replicate, two plants were used for measurement of leaf area and biomass. Leaf area was calculated by weighing all leaves of a plant and determining specific leaf area (leaf area/leaf mass) of foliar subsamples (by leaf area meter MK2, Eijkelkamp, Holland)[10]. At the end of the growing season, wilt diseases were assessed in each plot. The main stem of each plant was cut near the ground and rated on a scale of 0-5, in which 0= no discoloration, 1= 1 to 10% discoloration, 2= 11 to 30% discoloration, 3= 31 to 50% discoloration, 4= 51 to 75% discoloration and 5= 76 to 100% discoloration[11].

Statistical analyses were performed on all the data by using MSTAT-C. Analysis of variance (ANOVA) was used to evaluate the statistical difference of treatment means. The level of significance was set at $p<0.05$. Tukey's HSD test was conducted for pairwise comparisons.

RESULTS

Observations of foliar symptoms and vascular discolorations of roots and stems of the grafted and control plants revealed that the soil in the study area was not infested by *Verticillium*, *Fusarium* and nematodes.

There was no significant difference in the total fruit yields between the control and grafted plants and between the cultivars in 2002 and 2003 (Table 2). However, interaction between the rootstock and cultivar caused a 67% reduction and a 90% increase in the total fruit yields of the grafted plants of Faselis and Pala in 2003, respectively ($p<0.01$). A significant difference existed between mean fruit weights, depending on grafting ($p<0.05$) and cultivars ($p<0.01$) in 2002, but in 2003 ($p>0.05$). In 2002, mean fruit weight of the grafted plants was 9% higher than that of the control ones. Pala-*S. torvum* gave the largest mean fruit weight of 141 g in all the years.

Fruit width did not differ between the control and grafted plants and between the cultivars in 2002 (Table 2). In 2003, fruit width differed significantly, depending on the cultivars ($p<0.01$) and rootstock-cultivar interaction ($p<0.05$) (Table 2). Mean fruit width of Faselis (49 mm) was greater than that of Pala (45 mm), with the greatest fruit width obtained from the control plants of Faselis (51 mm). Although mean fruit length was 7% higher in the grafted plants than the control plants in 2002 ($p<0.05$), there was no significant difference in 2003 (Table 2). Pala fruits were 14-23% longer than Faselis ones, with the longest fruits obtained from the combination of Pala-*S. torvum* (17 cm) in all the years ($p<0.05$).

The results indicated that there was no significant difference in fruit juice pH between the control and grafted plants of the cultivars in 2002 ($p>0.05$) (Table 3). However, pH of Pala (5.59) was higher than that of Faselis (5.49) in 2003 ($p<0.01$). Grafting resulted in a significant reduction ranging from 12 to 20% in oxalic acid content, regardless of the cultivars in all the years ($p<0.01$). Similarly, oxalic acid content of Faselis was 9-20% lower than that of Pala ($p<0.05$). Soluble solid content of fruit juice was also found to be affected significantly by rootstock and cultivar in 2002 and 2003. Fruit soluble solid content of Pala was 6-21% higher than that of Faselis, while that of the control plant fruits was 6-14% greater than that of the grafted ones.

As shown in Table 4, the cultivars had a significant effect on plant height ($p<0.05$) and stem diameter ($p<0.01$) in 2002 and 2003. The plants of Pala grew longer (94-207 cm) and thicker (19-38 mm) than those of Faselis (73-158 cm long and 15-26 mm wide). The variables were also affected significantly by the rootstock and

Table 2: Mean values and mean comparisons of Pala and Faselis eggplant cultivars grown with or without rootstock on standard and biennial cultural systems for several fruit characteristics

		Fruit characteristic											
		Yield (kg plant^{-1}) Cultivar			Weight (g) Cultivar			Width (mm) Cultivar			Length (cm) Cultivar		
Year	Rootstock	Pala	Faselis	Mean	Pala	Faselis	Mean	Pala	Faselis	Mean	Pala	Faselis	Mean
2002	Control	1.84	2.21	2.03	119b	112b	116 B	44	48	46	15.1b	12.5c	13.8B
	S. torvum	1.59	1.64	1.62	141a	111b	126 A	44	46	45	16.7a	12.5c	14.6A
	Mean	1.72	1.93		130A	112B		44	47		15.9A	12.5B	
	p<	Rs, Cv and Int: ns			Rs:*; Cv:**; Int:*			Rs, Cv and Int: ns			Rs:*; Cv:**; Int:*		
2003	Control	3.32 ab	6.62a	4.97	108c	137ab	123	44b	51a	48	14.5b	15.3ab	14.9
	S. torvum	6.30ab	2.17b	4.23	140a	116bc	128	46b	47ab	47	17.1a	13.4b	15.3
	Mean	4.81	4.39		124	126		45B	49A		15.8A	14.4B	
	p<	Rs and Cv:ns; Int: **			Rs and Cv:ns; Int: **			Rs:ns; Cv:**; Int: *			Rs:ns; Cv:*; Int: **		

p = Probability; Rs = Rootstock; Cv = Cultivar; Int = Interaction; * = Significant at 5%, ** = Significant at 1%; ns = Non significant. Values followed by different small letter within the columns and rows and capital letter(s) in each column and row are significantly different by Tukey's Honestly Significant Difference (HSD) test

Table 3: Mean values and mean comparisons of Pala and Faselis eggplant cultivars grown with or without rootstock on standard and biennial cultural systems for several fruit quality characteristics

		Fruit characteristic								
		pH Cultivar			Oxalic acid (%) Cultivar			Soluble solid (°Brix) Cultivar		
Years	Rootstock	Pala	Faselis	Mean	Pala	Faselis	Mean	Pala	Faselis	Mean
2002	Control	5.55	5.46	5.51	0.164	0.157	0.161A	5.26a	5.25a	5.26A
	S. torvum	5.56	5.54	5.55	0.152	0.132	0.142B	5.23a	4.67b	4.95B
	Mean	5.56	5.50		0.158A	0.144B		5.25A	4.96B	
	p<	Rs, Cv and Int: ns			Rs:**; Cv:*; Int: ns			Rs, Cv and Int: **		
2003	Control	5.57	5.48	5.53	0.096	0.074	0.085A	5.40	4.51	4.96A
	S. torvum	5.60	5.49	5.54	0.075	0.062	0.068B	4.82	3.90	4.36B
	Mean	5.59A	5.49B		0.085A	0.068B		5.11A	4.21B	
	p<	Rs:ns; Cv:**; Int:ns			Rs and Cv:**; Int: ns			Rs and Cv:**; Int: ns		

p = Probability; Rs = Rootstock; Cv = Cultivar; Int = Interaction; * = Significant at 5%, ** = Significant at 1%; ns = Non significant; Values followed by different small letter within the columns and rows and capital letters in each column and row are significantly different by Tukey's Honestly Significant Difference (HSD) test

Table 4: Mean values and mean comparisons of Pala and Faselis eggplant cultivars grown with or without rootstock on standard and biennial cultural systems for several plant growth characteristics

		Plant characteristic											
		Length (cm) Cultivar			Stem diameter (mm) Cultivar			Leaf area (cm^2) Cultivar			Biomass (g) Cultivar		
Year	Rootstock	Pala	Faselis	Mean	Pala	Faselis	Mean	Pala	Faselis	Mean	Pala	Faselis	Mean
2002	Control	94	76	85	18.3	15.3	16.8	4544	3908	4226	613	319	466
	S. torvum	94	69	82	20.5	14.6	17.5	4535	4475	4505	573	300	436
	Mean	94A	73B		19.4A	14.9B		4539	4191		593A	310B	
	p<	Rs:ns; Cv :*; Int:ns			Rs:Ns; Cv :**; Int:ns			Rs, Cv and Int:ns			Rs:ns; Cv :**; Int:ns		
2003	Control	203a	184a	194A	24.9b	23.0b	24.0B	34558b	30918b	32738	2694b	1900bc	2297
	S. torvum	212a	131b	171B	50.6a	28.1b	39.3A	61762a	17742b	39752	4849a	1083c	2966
	Mean	207A	158B		37.7A	25.6B		48159A	24330B		3772A	1492B	
	p<	Rs:*; Cv :**; Int:*			Rs, Cv and Int:**			Rs:ns; Cv :**; Int:*			Rs:ns; Cv and Int:**		

p = Probability; Rs = Rootstock; Cv = Cultivar; Int = Interaction; * = Significant at 5%, ** = Significant at 1%; ns = Non significant; Values followed by different small letter within the columns and rows and capital letters in each column and row are significantly different by Tukey's Honestly Significant Difference (HSD) test

rootstock-cultivar interaction in 2003. Average height of the control plants was found to be 13% higher than that of the grafted plants ($p<0.05$). Grafting decreased the plant height of Faselis by 24% ($p<0.05$), but that of Pala. Stem diameter of the grafted plants was found to be 64% greater than that of the control ones, with the highest stem diameter obtained from the grafted plants of Pala (51 mm) ($p<0.01$).

Leaf area did not appear to be affected significantly by the rootstock and the cultivar in 2002 (Table 4). There were significant effects of the cultivars ($p<0.01$) and rootstock-cultivar interaction ($p<0.05$) on leaf area in 2003, although grafting had no effect ($p>0.05$). Grafted plants of Pala had the greatest leaf area (61762 cm^2 $plant^{-1}$), while grafted plants of Faselis had the lowest leaf area (17742 cm^2 $plant^{-1}$) (Table 4).

Significant effects of the cultivars on biomass were observed in the period 2002-2003 ($p<0.01$) (Table 4). Pala biomass was 91-153% greater than Faselis biomass. Biomass was affected by the rootstock-cultivar interaction in 2003 ($p<0.01$). The greatest biomass recorded in the grafted plants of Pala was 4849 g $plant^{-1}$, whereas the lowest biomass recorded in the grafted plants of Faselis was 1083 g $plant^{-1}$ (Table 4).

DISCUSSION

Our findings revealed that grafting had significant effects on fruit yield and quality and plant growth, but the effects varied depending on the cultivars when plants were grown biennially in non-infested soils.

Grafting reduced the yield of Faselis by 67% compared to that of the control plants in the second year, while there was no significant difference in the first year. Similar yield reduction was reported when some muskmelon cultivars was grafted onto *Benincasa hispida*[12]. Bletsos *et al.*[6] also showed that yield of grafted eggplants on *S. torvum* varied with years. Unlike Faselis, grafting did not reduce the fruit yield of Pala when grown in the two years, but the advantage of grafting on mean fruit yield of Pala in the both years was not statistically significant.

Grafting did not affect fruit quality such as mean fruit weight, width, length and juice pH in Faselis in the both production years, but the soluble solid and oxalic acid contents. The effect of grafting on fruit quality of Pala varied. Grafting improved the physical fruit quality such as fruit weight and length but decreased chemical fruit quality such as the oxalic acid content over the years. The effects of grafting on soluble solid content were more pronounced in 2002 than in 2003.

It seems that utilization of the grafted material effects on fruit quality parameters are scion/rootstock specific. For example, fruit quality due to grafting was reported as unaffected for several studies[6,12-14]. However, the negative effect of grafting on different fruit quality parameters was also reported in vegetables[3] and melons[12]; although there have been contrary results in eggplant[6] and watermelon [13].

As with fruit yield and quality, the results from the Faselis indicated that growing the same grafted plants during the two successive years had negative effects on plant growth, probably due to incompatibility in 2003. Therefore, *S. torvum* was not a suitable rootstock for Faselis in biennial eggplant production. Miller and Crocker[15] did not recommend *Diospyros lotus* as a rootstock for some cultivars of *Diospyros khaki* L. because of graft incompatibility in later years. It was also reported that watermelon grafted onto *Cucurbita* type rootstocks was reported to produce a lower yield and poor fruit quality, due to incompatibility, relative to *Lagenaria* rootstock[13].

Unlike Faselis, grafting significantly increased the stem diameter, leaf area and biomass of Pala, when compared to control ones in 2003, whereas the other growth parameters in 2002 were not influenced by grafting. Present findings revealed that vegetative growth and yield were affected by cultivar characteristics, as supported by Lee[3]. This could be attributed to their different growth characteristics, as Pala is more vigorous than Faselis and to their different graft affinity and compatibility with the rootstock. Since *S. torvum* is a vigorous rootstock, it must be combined with vigorous cultivar to obtain equal or higher yields compared to a combination of weak cultivar and vigorous or weak rootstock, respectively[8].

In conclusion, grafting can be used in biennial growing for Pala, but in Faselis with the consideration of fruit yield, quality and plant growth parameters. Such promising results suggested that this system could be used successfully in Mediterranean countries such as Turkey. However, since the success of this system was proved to be genotype dependent, the affinity and compatibility of other eggplant cultivars with *S. torvum* needs to be investigated, especially for greenhouse cultivation. In addition, biennial eggplant growing by using grafted seedlings may be more profitable and ecologically sustainable than conventional ones. The benefits of utilization of the rootstock even might be more profound in soil infested with pathogen such as *Verticillium* wilt[6]. Therefore, economic and ecological productivity of this system is of considerable value and needs to be further explored in the context of global food and environmental securities.

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