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RESPONSE OF DIFFERENT ROOTSTOCKS ON VEGETATIVE GROWTH, FRUIT AND SEED YIELD OF EGGPLANT (*Solanum melongena* L.)

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In this study, different eggplant scion genotypes were grafted onto different eggplant rootstock genotypes in order to assess the plant growth, development, and fruit yield of eggplant plants based on the physiological and morphological response mechanisms. The experiment was conducted at the vegetable research field plot on the campus at Faculty of Agriculture, University of Erciyes, Kayseri-Turkey. The field experiment was carried out to determine plant growth, shoot and root fresh and dry biomasses, plant height, total leaf area, leaf chlorophyll index (SPAD), rootstock and scion stem diameter, number of fruits per plant, total fruit yield, fruit dry matter, fruit diameter and length, total seed yield, and thousand seed weight. Two eggplant cultivars (Topan and Pala) were grafted onto two different eggplant rootstock genotypes (Hawk and Köksal F1), while non-grafted scion genotypes were used as control plants. The experiment was laid in a randomized completely block design (RCBD) containing three replications. The results indicated that between grafted and non-grafted plants significant (*P*<0.001) differences were observed in shoot and root fresh and dry biomasses, plant height, total leaf area, leaf chlorophyll index (SPAD), rootstock and scion stem diameter, number of fruits per plant, total fruit yield, fruit dry matter, fruit diameter and length, total seed yield, and thousand seed weight. The rootstocks utilized have influenced the vigour of the grafted plants. The 'Pala' grafted on the rootstock 'Köksal F1' registered 61.91% increment in shoot fresh biomass and 49.04% increment in root fresh biomass in comparison to the non-grafted plants. Grafting influenced plant height which reached values of roughly 1.0 m, leaf area

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resulting in values of 5645.04 cm^2 $plant^{-1}$, and SPAD resulting in values of 47.48 at 'Pala/Köksal F1' graft combination in comparison to the non-grafted plants. The grafting combinations also influenced the productivity of plants as compare to non-grafted plants. The significantly highest fruit yield obtained from 'Pala/Köksal F1' graft combination was of 4711.89 g $plant^{-1}$, followed by 'Topan/Köksal F1' graft combination with 3834.54 g $plant^{-1}$. 'Pala' was produced 11.49 number of fruits per plant when grafted on the 'Köksal F1' rootstock and 8.46 number of fruits per plant when grafted on the 'Hawk' rootstock. Regarding seed yield, 'Pala' grafted on the rootstock 'Köksal F1' registered 72.03% increment in total seed yield in comparison to the non-grafted plants. Overall, the eggplant rootstock genotypes 'Köksal F1' showed a better performance shoot and root fresh and dry biomasses, plant height, total leaf area, leaf chlorophyll index (SPAD), rootstock and scion stem diameter, number of fruits per plant, total fruit yield, fruit dry matter, fruit diameter and length, total seed yield, and thousand seed weight as compared to non-grafted plants.

Keyword: eggplant, fruit diameter, rootstock, SPAD, yield

INTRODUCTION

Eggplant (*Solanum melongena* L.), belonging to the Solanaceae family, is the most important and extensively consumed vegetable in the world. It is the world's sixth most important vegetable after tomato, watermelon, onion, cabbage, and cucumber. It is widely cultivated in Asia and to a lesser but still important extent in the Mediterranean basin, including Turkey. The estimated total world production for eggplants in 2017 was 52.309.119 metric tons, up by 2.2% from 51.192.811 tons (FAO, 2018). China was by far the largest producer of eggplants, accounting for over 62% of global production (FAO, 2018). Eggplant fruits have a reasonable nutritional value and can be compared with the value of tomato. The chemical composition and the texture of eggplant fruits make them attractive for human consumption all over the world. Quality comprises odor, flavor, nutritional value, health associated anti-oxidative compounds and physical appearance of vegetables. Due to its phenolic constituents, it has oxygen radical scavenging capacity and is ranked in the top ten nutritionally important vegetables (HANSON *et al.,* 2006). The fresh weight of the eggplant fruit is composed of 1.4% protein, 0.3% minerals (B, Fe, I, Mg), 0.3% fat, 1.3% fiber, 92.7% water and the remaining 4% consisting of various carbohydrates and vitamin A, B and C (KHAN, 1979). The young and almost mature fruits are used as vegetable, they may be roasted, fried, stuffed, cooked as curry, pickled or prepared in some other manner; in Indonesia and Malaysia they are also eaten raw (SUTARNO *et al.,* 1993).

Vegetable quality depends on genetic, environmental and cultural factors and their interactions; on cultural factors such as growing medium (soilless or in soil) and water quantity and quality, mineral nutrition and salinity (ROUPHAEL *et al.,* 2012). Besides vegetable quality, gaining more yield is also important issue in eggplant production. The yield loss in eggplant is associated with biotic as well as abiotic stresses (SHAHBAZ and ASHRAF, 2013). Biotic factors such as soilborne diseases arising from continuous cropping are major problems that limit productivity in eggplant (BLETSOS *et al.,* 2003). Therefore, improving soilborne resistance is one of the major scientific and economic challenges in eggplant. High and low temperature

(NOTHMANN *et al*., 1979), drought (AMIRI *et al.*, 2012), heavy metal toxicity (KIRAN *et al.*, 2014) and salinity (HANACHI *et al.*, 2014) are abiotic factors involved in yield loss of eggplant. Solving biotic and abiotic problems will have a positive effect on crop yield and production. One possible way to reduce the detrimental effects of biotic and abiotic stresses on high-yielding cultivars might be to graft them onto rootstocks with the capability of inducing biotic and abiotic stresses tolerance to the scion (LEE, 1994). Grafting is defined as natural or a deliberate fusion of two or more living plant parts so that vascular continuity is established between them (PINA and ERREA, 2005) and the resultant genetically composite organism functions as a single plant (MUDGE *et al.*, 2009). The fusion allows the grower to combine a scion possessing desirable fruit producing traits with a rootstock that may be resistant to a multitude of biotic and abiotic stresses, resulting in a more productive plant (PETRAN and HOOVER, 2014). In vegetable production, grafting was first practiced in Korea and Japan in the early 20th century when watermelon (*Citrullus lanatus*) was grafted onto squash rootstock (*Cucurbita moschata*) to overcome fusarium wilt (KING *et al.,* 2010). As for the Solanaceae family, the first record was of eggplant (*Solanum melongena* L.) grafted on scarlet eggplant (*Solanum integrifolium P.*) in the 1950s (ODA, 1998), while tomato grafting was introduced commercially in the 1960s (LEE and ODA, 2003; BLETSOS and OLYMPIOS, 2008). The advantages of grafting are tolerance against high and low temperatures, flooding, (KING *et al.,* 2010) drought, salinity, heavy metals, enhanced growth, vigour, yield and quality (LEE, 1994; RIVERO *et al*., 2003; BLETSOS AND OLYMPIOS, 2008; DAVIS *et al*., 2008; COLLA *et al*., 2014). Eggplant rootstocks are more efficient for water uptake than their tomato counterparts (COLLA *et al*., 2014) due to their dense and extensive root systems (BLETSOS and OLYMPIOS, 2008). They are better adapted to hot arid climate, performs better under wet conditions and can serve as rootstocks for tomato under these conditions to optimize yield (BLACK *et al*., 2003; PALADA and WU, 2008). PASSAM *et al.* (2005) stated 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. In another study, eggplant rootstock cv. "Yuanqie" grafted onto a heat-tolerant rootstock cv. "Nianmaoquie" resulted in a prolonged growth stage and yield increase of up to 10% (WANG *et al.,* 2007). KHAH (2005) confirmed that, eggplant seedling 'Rima' was grafted on to two tomato rootstocks, in the field and greenhouse conditions. Grafted plants produced 53% and 60% more fruits than non-grafted plants respectively. Similar increases in eggplant yield as a result of grafting have also been observed (LEE, 1994; BLETSOS *et al.*, 2003). Vegetable grafting has been a standard procedure for many greenhouse processes. Temporarily the technology has also gained momentum under open field conditions (RODRIQUEZ and BOSLAND, 2010) and further research is still underway to evaluate its application thereunder (KUBOTA *et al.,* 2008). Furthermore, the effect of grafting on fruit quality of watermelon has been much more widely studied than the effect of grafting on tomato or eggplant fruit quality. Therefore, this study was investigated related to the grafting of eggplant (*Solanum melongena* L.) onto different eggplant rootstock genotypes in order to assess the plant growth and development, fruit and seed yield of eggplant plants based on the physiological and morphological response mechanisms.

MATERIALS AND METHODS

Plant material, treatments and experimental design

The experiment was conducted in the 2018 growing season at the vegetable research field plot on the campus at Faculty of Agriculture, University of Erciyes, Kayseri, in Turkey (38° 43' 56" N, 35° 29' 7" E). Six treatments were used, i.e. two scion cultivars (Topan and Pala) grafted onto two rootstocks (Hawk and Köksal) and two non-grafted cultivars (control). The seeds were sown in 72-cell seedling trays (W 280 × L 540 × H 45 mm, IBK Iklim Bahce Co., Ltd., Turkey) in a mixture of peat (pH: 6.0-6.5) and perlite (2v:1v) under a temperature regime of 25/22 °C (day/night), the relative humidity was 65-70% and about 350 μmol m^{-2} S^{-1} photon flux in a controlled growth chamber. Trays were watered manually every day to maintain the substrate at water holding capacity. Grafting was done with “tube grafting” described by LEE, (1994) on May 9th, 2018, when both scion and rootstock plants have had stem diameters of 2-3 mm thick; because grafting compatibility is dependent on similar values of thickness. Grafting was carried out in a laboratory conditions, in a shady place sheltered from the wind, to avoid wilting of the grafted plants. Briefly, the shoot tip of the rootstock was cut off below the cotyledons at an angle of 45 with the same for the scion above the cotyledons. The grafting position was fixed firmly with a tubular silicone clip (1.5 mm whole diameter). After grafting, plants were healed and acclimatized in the tunnel covered with double-layered plastic film and shade cloth in the climate chamber for one week (LEE *et al.*, 2010). In order to prevent grafted plants from wilting by the excessive transpiration and to enhance healing, the tunnel was closed for the first three or four days of healing and acclimatization period. For the next three or four days, the opening and closing of the tunnel were done depending on the conditions of grafted plants and growth room. This was done for the acclimatization of grafted plants to environmental conditions outside tunnel. The grafted plants stayed at the healing and acclimatization period totally for ten days. After the end of healing and acclimatization, grafted plants were transplanted to the field on June 5th, 2018, 1.0-meter between rows and 0.5-meter apart within the rows were used during transplanting and drip irrigated. The experiment was implemented in a randomized completely block design containing three replications. All cultural practices recommended for eggplant cultivation on field conditions were adopted uniformly according to crop requirements. Average daily temperature during the experimental period from May to September of 2018 was obtained from the meteorological station. Four plants were selected randomly and tagged from each replicate and measurement were made on these plants for yield and other morphological traits, while the others remained as guard plants and were not included in the evaluations. Measurements were made on the same plants throughout the growing season. Harvesting was done on September, 19th 2018. At the end of the harvest, plants were pulled up from the soil and bought to the Plant Physiology Laboratory, Erciyes University.

Harvest, shoot and root fresh-dry weight, yield and fruit diameter-length determination

At the end of the experiment, plants were harvested by separating them into shoot, fruits and roots. Fruit diameter and length were measured from the five randomly selected fruits at the vegetative maturity stage with the help of calipers with the diameter and length were expressed in millimeters. Number of fruits per plant was recorded by counting the number of fruits at each harvest and the total number of fruits from each harvest was recorded and expressed as a number. Total fruit fresh weight was recorded by taking the weight of five fruits from each tagged plant in successive harvests and the mean weight of the fruits was recorded and expressed in kilograms. The fruit yield per plant was measured by taking a weight of eggplant fruits from five tagged eggplant plants from each plot at each harvest. The total fresh weight of fruit of all harvests was summed up and expressed in kilograms. The fruits were harvested at the fully ripe stage. For the total dry fruit weight determination, fruits were dried in a forced-air oven for 72 h at 70°C. The stem diameter of scion was measured above the grafting area, though the stem diameter of the rootstock was measured under the grafting area of the grafted plant. For the fresh weight determination shoot was fractioned into the leaf, stem, and roots. In order to determine shoot and root dry weight, plant materials were dried in a forced-air oven for 72 h at 70°C.

Plant height, total leaf area and leaf chlorophyll index (SPAD) measurements

Plant height (cm) was measured by using a ruler. The total leaf area (LA) of plants was measured destructively with a leaf area measuring device (LI-COR LI-3100C, Inc., Lincoln, NE, USA). The measurements were recorded in centimeter square (cm^2). For each experimental treatment, SPAD readings were taken with the Minolta SPAD-502 chlorophyll meter. During the growth period, two series of SPAD 502 chlorophyll meter readings were performed at the centre of the leaves on the fully expanded youngest leaf of whole plants for each treatment. Seed extracted from fruits were weighed using sensitive balance and mean values were calculated. Thousand seed weight was carried out according to the ISTA rules (ISTA, 1996).

Statistical analysis

Analysis of variance (ANOVA) was performed using the SAS program (SAS 9.0, SAS Institute Inc., Cary, NC, USA). If ANOVA determined that the effects of the treatments were significant (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$, and ns means not significant for F-Test), then the treatment means were separated by Duncan's Multiple Range Test ($P < 0.05$). Pearson correlation coefficients were calculated using the PROC CORR procedure of SAS.

RESULTS AND DISCUSSION

Shoot and root biomass production

At the end of crop cycle, grafting significantly ($P<0.001$) influenced shoot- root fresh and dry biomasses (Table 1). Scion and rootstock genotypes differed for plant growth and morphology. In general, shoot fresh and dry biomasses were higher in grafted eggplant plants than non-grafted plants. Also, both 'Topan' and 'Pala' scion genotypes grafted onto both rootstocks ('Köksal F1' and 'Hawk') had higher values of the previous parameters than non-grafted ones. 'Köksal F1' as rootstock had beneficial effect on shoot fresh and dry biomasses than 'Hawk' one for both scion genotypes of 'Topan' and 'Pala'. Though, 'Pala' scion grafted onto 'Köksal F1' rootstocks produced significantly the highest shoot fresh (564.0 g $plant^{-1}$) and dry matter (62.67 g $plant^{-1}$), respectively but response of 'Topan' scion genotype to grafting was more effective on previous parameters. Shoot fresh and dry biomasses were increased by almost

61.91% and 100.95%, respectively in ‘Pala’ grafted onto ‘Köksal F1’ and by almost 12.17% and 26.41%, respectively when ‘Hawk’ used as rootstock. However, shoot fresh and dry biomasses were increased by almost 50.92% and 126.38%, respectively in ‘Topan’ scion genotype grafted onto ‘Köksal F1’ and by 19.09% and 47.79%, respectively as grafted onto ‘Hawk’ rootstock. Similar to our results, grafting onto eggplant rootstock of Beaufort F1 caused promoted vegetative growth and development on eggplant plants (JOHNSON *et al.,* 2014). MOHAMED *et al.* (2014) also concluded that grafted plants produce much more foliage and vigorous plants compared to non-grafted plants.

Table 1. Effect of graft combination on shoot and root fresh-dry matters of eggplants

Graft Combination	Shoot fresh weight (g plant^{-1})	Shoot dry weight (g plant^{-1})	Root fresh weight (g plant^{-1})	Root dry weight (g plant^{-1})
Topan	314.52 f	26.19 f	49.47 f	7.43 f
Topan/Köksal F1	474.22 b	59.28 b	66.29 b	11.05 b
Topan/Hawk	374.22 d	38.70 d	58.67 d	8.38 d
Pala	348.33 e	31.19 e	52.04 e	8.14 e
Pala/Köksal F1	564.00 a	62.67 a	77.57 a	12.93 a
Pala/Hawk	394.22 c	39.42 c	61.81 c	10.30 c
F Test				
Graft combination	***	***	***	***

[1] Values denoted by different letters are significantly different between genotypes within columns at P < 0.05 (T-Test). ns, non-significant. *P < 0.05, **P < 0.01 and ***P < 0.001 (F-Test).

In terms of root growth, ‘Pala’ grafted onto ‘Köksal F1’ produced significantly highest root fresh and dry biomasses (Table 1). Grafting of ‘Pala’ onto ‘Köksal F1’ increased the root fresh and dry biomasses by 49.04% and 58.82% compared to 26.41% and 18.77% of increment when grafted onto ‘Hawk’ rootstock, respectively. Moreover, grafting of ‘Topan’ scion genotypes onto ‘Köksal F1’ increased the root fresh and dry biomasses by 34.01% and 48.70% compared to 18.60% and 12.80% of increment as grafted onto ‘Hawk’, respectively. In our study it was clearly observed that the scion varieties weak root system can be improved by grafting with using an appropriate rootstock. Our results are consistent with those obtained by YETISIR and SARI (2019); ULAS (2019); ULAS *et al.* (2019) and ULAS *et al.* (2019a, b) who reported that grafted plants had significantly higher shoot and root dry matter than non-grafted plants. The reason might be because of the high vigor of varieties of rootstocks and scions used in those studies.

Plant height, leaf area, leaf chlorophyll index (SPAD), rootstock and scion stem diameter

Plant height, leaf area, leaf chlorophyll index (SPAD), rootstock and scion stem diameter of the eggplant plants have been significantly influenced by the rootstocks, leading to a higher plant growth and development (Figure 1, Table 2). Plant height at final harvest varied between 66.94 and 98.93 cm plant^{-1} for non-grafted ‘Topan’ and ‘Pala/Köksal F1’ graft combination, respectively (Figure 1). The maximum significant values of plant height, leaf area, leaf chlorophyll index (SPAD), rootstock and scion stem diameter were recorded in 'Pala' grafted onto 'Köksal F1' than non-grafted and other graft combinations (Figure 1, Table 2).

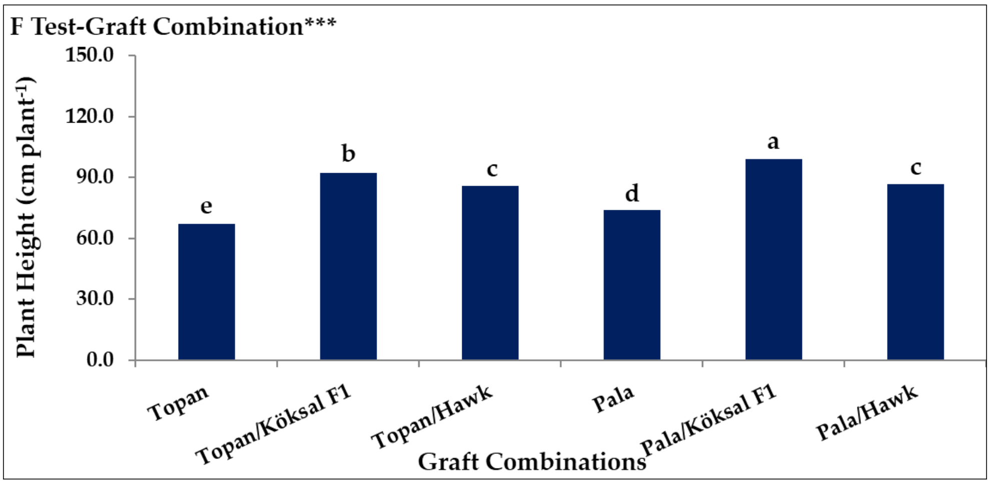

Figure 1. Effect of graft combination on plant height of eggplants. Bars marked by different letters are significantly different between eggplant genotypes within bars on the figure at P < 0.05. *P < 0.05, **P < 0.01 and ***P < 0.001.

Table 2. Effect of graft combination on total leaf area, leaf chlorophyll index (SPAD), rootstock and scion diameter of eggplants

Graft Combination	Total leaf area (cm^2 $plant^{-1}$)	Leaf chlorophyll index (SPAD)	Rootstock diameter (mm $plant^{-1}$)	Scion diameter (mm $plant^{-1}$)
Topan	4058.67 f	43.23 e	21.56 f	18.56 f
Topan/Köksal F1	5075.22 b	46.52 b	25.43 b	22.55 b
Topan/Hawk	4389.89 d	45.39 c	23.51 d	20.51 d
Pala	4132.33 e	44.40 d	22.48 e	19.48 e
Pala/Köksal F1	5645.04 a	47.48 a	26.70 a	23.70 a
Pala/Hawk	4732.33 c	45.54 c	24.39 c	21.39 c
F Test				
Graft combination	***	***	***	***

[1] Values denoted by different letters are significantly different between genotypes within columns at P < 0.05 (T-Test). ns, non-significant. *P < 0.05, **P < 0.01 and ***P < 0.001 (F-Test).

Grafting of 'Pala' scion genotype onto 'Köksal F1' increased the plant height by 33.89%, as well as by 17.18% when grafted onto 'Hawk'. Grafting of 'Topan' scion genotype onto 'Köksal F1' increased the plant height by 37.93%, as well as by 28.50% when grafted onto 'Hawk'. HOZA *et al.,* (2017) stated that the plant height has been influenced by the rootstocks, leading to a higher plant growth in eggplant. Similar results were obtained by KHAH (2011), ADAM (2018), ULAS (2019), ULAS *et al.* (2019), KOMBO and SARI (2019) and YUCEL (2020). In terms of leaf area, the significantly highest increment of leaf area (36.61%) was recorded in 'Pala' grafted onto 'Köksal F1' followed by 25.05% of increment in 'Topan' grafted onto 'Köksal F1'. Up to now in many crop species such as cucumber, watermelon, tomato, eggplant and pepper it was stated that grafted plants produced more leaf area and specific leaf area than non-grafted plants (SOLTAN MAHMOUD *et al.,* 2017). On the other hand, KHAH (2011) stated that there were no significant differences observed in leaf area between grafted, non-grafted and self-grafted eggplant plants. Regarding leaf chlorophyll index (SPAD), 'Topan' grafted onto 'Köksal F1' had the significantly highest increment of leaf chlorophyll index (SPAD) 7.61% followed by 6.92% of increment in 'Pala' grafted onto 'Köksal F1'. Likewise, 'Topan' grafted onto 'Hawk' had the significantly highest increment of leaf chlorophyll index (SPAD) (5.00%). YUCEL (2020) observed that SPAD value of eggplant plants was significantly higher under both low and high nitrogen conditions depending on the rootstock genotypes than non-grafted plants. Similar results were obtained by ADAM (2018) on tomato genotypes and by ULAS (2019) on pepper genotypes. Concerning rootstock and scion stem diameter, grafting of 'Pala' scion genotype onto 'Köksal F1' increased the rootstock stem diameter of plant by 18.74% over the control, followed by 17.95% as grafted 'Topan' scion genotype onto 'Köksal F1'. Furthermore, grafting of 'Pala' scion genotype onto 'Köksal F1' increased the scion stem diameter of plant by 21.63% over the control, followed by 21.44% as grafted 'Topan' scion genotype onto 'Köksal F1'. Generally, grafted plants have bigger stem diameter as compared to non-grafted plants. Pepper plants enhanced scion and rootstock diameter in different ratios depending on the rootstock genotypes than non-grafted control plants. On the other hand, deleterious effects on scion and rootstock diameter has also been reported (ULAS, 2019). The reason might be due to a graft incompatibility between rootstock and scion varieties that could be regarding with the repair of the conducting vascular tissues (xylem and phloem) and the encouragement or impairment of the graft growth as a result of modifications of the flow of water and nutrients (MUDGE and JANICK, 2009).

Total yield, number of fruits per plant, fruit dry matter, fruit diameter and fruit length

The results obtained from this experiment indicated that highly significant differences (P<0.001) were found among the graft combinations in total yield, number of fruits per plant, fruit dry matter, fruit diameter and fruit length (Figure 2, Table 3). The maximum significant value of total yield was recorded in 'Pala' scion genotype grafted onto 'Köksal F1' (4711.89 g plant^{-1}) with 92.01% of increment, followed by 81.82% of increment in 'Topan' grafted onto 'Köksal F1' (3854.34 g plant^{-1}) over the non-grafted ones (Figure 2).

Data from the literature has showed that the eggplant cultivar 'Rima' grafted on the tomato rootstock formed 53% and 60% more fruits respectively in comparison to control in greenhouse and in field (KHAH, 2005). JOHNSON *et al.,* (2014) also stated that grafting onto eggplant rootstock of Beufort F1 caused more fruit yield compared to non-grafted control plants.

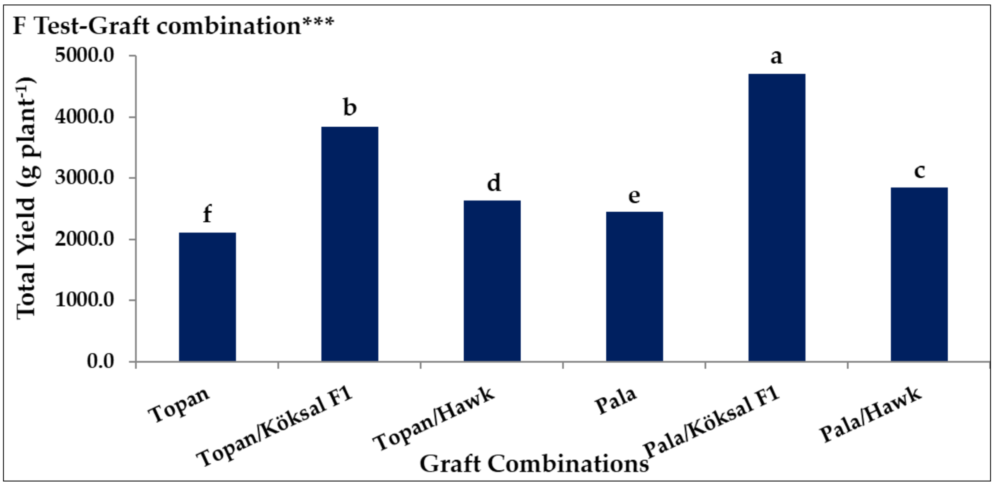

Figure 2. Effect of graft combination on total yield of eggplants. Bars marked by different letters are significantly different between eggplant genotypes within bars on the figure at $P < 0.05$. *$P < 0.05$, **$P < 0.01$ and ***$P < 0.001$.

Table 3. Effect of graft combination on number of fruits per plant, fruit dry matter, fruit diameter and fruit length of eggplants

Graft Combination	Number of fruits per plant	Fruit dry matter (g plant^{-1})	Fruit diameter (cm fruit^{-1})	Fruit length (cm fruit^{-1})
Topan	5.69 f	203.89 f	5.21 e	12.57 f
Topan/Köksal F1	9.61 b	319.55 b	8.60 b	17.53 b
Topan/Hawk	7.55 d	220.00 d	6.65 c	15.49 d
Pala	6.67 e	210.89 e	5.76 d	14.46 e
Pala/Köksal F1	11.49 a	362.45 a	10.59 a	19.40 a
Pala/Hawk	8.46 c	223.09 c	6.59 c	16.45 c
F Test				
Graft combination	***	***	***	***

[1] Values denoted by different letters are significantly different between genotypes within columns at $P < 0.05$ (T-Test). ns, non-significant. *$P < 0.05$, **$P < 0.01$ and ***$P < 0.001$ (F-Test).

On the other hand, grafting has also been reported to confer deleterious effects on growth and yield. For example, tomato and eggplant grafted onto *Datura patula* exhibit less growth, lower production and smaller fruit size in comparison to non-grafted plants (BLETSOS and OLYMPIOS, 2008). Regarding number of fruits per plant, the maximum significant values of number of fruits per plant were recorded in ‘Pala’ grafted onto ‘Köksal F1’ than non-grafted or those grafted onto ‘Hawk’ rootstock plants. Grafting of ‘Pala’ onto ‘Köksal F1’ increased the number of fruits per plant by 72.18% as well as by 69% in ‘Topan’ grafted onto ‘Köksal F1’. Furthermore, grafting of ‘Topan’ onto ‘Hawk’ increased the number of fruits per plant by 32.77% as well as by 26.84% in ‘Pala’ grafted onto ‘Hawk’, respectively. Our results are in accord with those obtained by PASSAM *et al.* (2005); GISBERT *et al.* (2011); HOZA *et al.* (2017), and ULAS (2019) who stated that grafted plants produced significantly higher number of fruits than control plants. Concerning fruit dry matter, grafting of ‘Pala’ onto ‘Köksal F1’ resulted in accumulation of the maximum amount of dry weight in fruits (362.45 g fruit^{-1}) with increment 71.87%, followed by ‘Topan’ grafted onto ‘Köksal F1’ by 56.72% of increment over the non-grafted plants. However, increment % of fruit dry weight in ‘Pala’ and ‘Topan’ scion genotypes grafted onto ‘Hawk’ was very low. Our results are also consistent with those of GISBERT *et al.* (2011) and SABATINO *et al.* (2018), who reported that eggplants grafted onto interspecific hybrids produced consistently more fruits per plant than non-grafted ones. On the other hand, there were no significant differences observed in fruit dry matter between grafted and non-grafted plants such as pepper (OKA *et al.,* 2004), in tomato under greenhouse conditions (ULUKAPI and ONUS, 2005; AYDIN, 2006). Regarding fruit diameter and length, the maximum significant values of fruit diameter (10.59 cm fruit^{-1}) was achieved (with increment 83.93% over control) in ‘Pala’ grafted onto ‘Köksal F1’. Furthermore, the highest fruit length (19.40 cm fruit^{-1}) was found in ‘Pala’ grafted onto ‘Köksal F1’, although the highest increment in fruit length was 39.49% in ‘Topan’ grafted onto ‘Köksal F1’. Our results were in line with the results of SABATINO *et al.* (2019) who concluded that rootstock significantly influenced fruit length in eggplant. Eggplant fruits were significantly more elongated when grafted on *S. melongena* X *S. aethiopicum* gr. *gilo* hybrid rootstock than when grafted onto ‘Scarlatti’ rootstock or from ungrafted ‘Scarlatti’ plants, which in turn had more elongated fruits than those from plants grafted onto *S. aethiopicum* gr. *gilo.* Similar results were also obtained by GISBERT *et al.* (2011), who hypothesized that fruit shape changes are probably due to changes in the concentration of growth regulators induced by the rootstock. Our findings are in accord with those obtained SABATINO *et al.* (2018), who reported that rootstock significantly influences fruit width but has no significant effect on calyx length. Thus, it seems that, fruit shape in eggplant is highly heritable and under genetic control (MUÑOZ-FALCÓN *et al.,* 2008; PORTIS *et al.,* 2014) and even though rootstocks may affect cultivar fruit shape parameters due to changes in the concentration of growth regulators (GISBERT *et al.,* 2011), rootstock may differently affect specific fruit shape characters in relation to the scion genotype. Similar findings were observed in some vegetable plants like pepper (GISBERT *et al.*, 2010; TSABALLA *et al.*, 2013; DONAS-UCLES *et al.*, 2014) and watermelon (MIGUEL *et al*., 2004; KOMBO and SARI, 2019) larger fruits were observed when grafted on to rootstocks.

Total seed yield and thousand seed weight

The results obtained from this experiment indicated that highly significant differences (P<0.001) were found among the graft combinations in total seed yield and thousand seed weight (Figure 3 and 4). The total seed yield was ranged from 8.98-4.98 g fruit^{-1}. The maximum significant value of total seed yield was recorded in ‘Pala’ scion genotype grafted onto ‘Köksal F1’ (8.98 g fruit^{-1}) with 72.03% of increment, followed by 46.81% of increment in ‘Topan’ grafted onto 'Köksal F1' (7.31 g fruit^{-1}) over the non-grafted ones. Furthermore, grafting of 'Pala' onto 'Hawk' increased the total seed yield by 27.97% as well as by 20.08% in 'Topan' grafted onto 'Hawk', respectively (Figure 3).

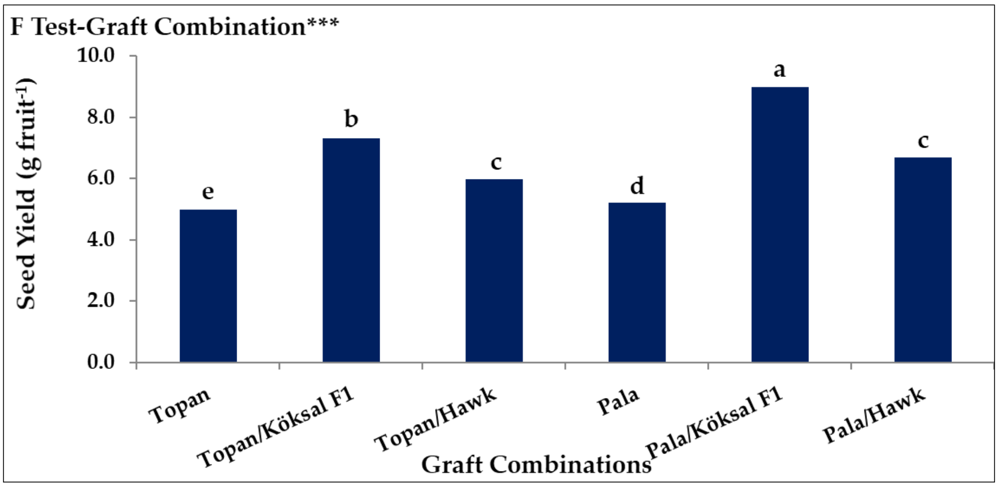

Figure 3. Effect of graft combination on total seed yield of eggplants. Bars marked by different letters are significantly different between eggplant genotypes within bars on the figure at P < 0.05. *P < 0.05, **P < 0.01 and ***P < 0.001.

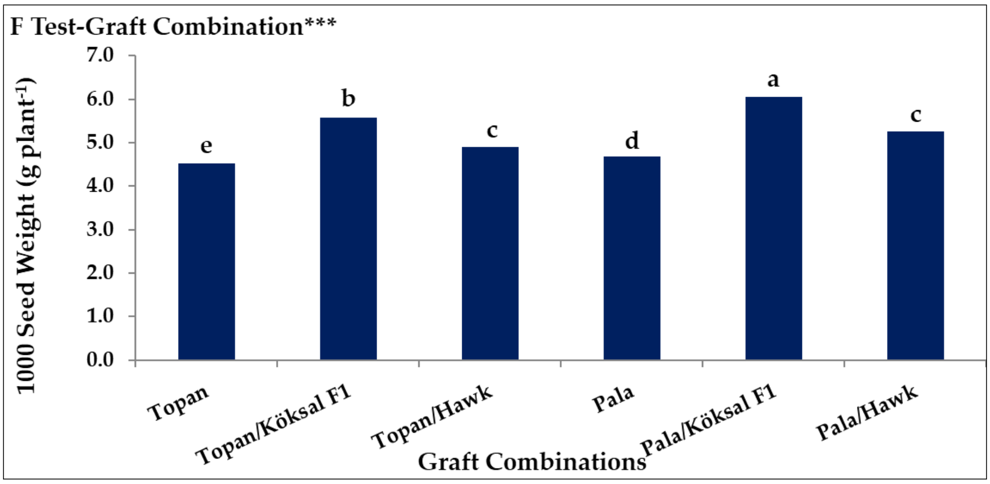

Figure 4. Effect of graft combination on 1000 seed weight of eggplants. Bars marked by different letters are significantly different between eggplant genotypes within bars on the figure at P < 0.05. *P < 0.05, **P < 0.01 and ***P < 0.001.

Regarding thousand seed weight, the maximum significant values of thousand seed weight was recorded in 'Pala' grafted onto 'Köksal F1' than non-grafted or those grafted onto 'Hawk' rootstock plants. Grafting of 'Pala' onto 'Köksal F1' increased the thousand seed weight by 29.59% as well as by 23.13% in 'Topan' grafted onto 'Köksal F1'. Furthermore, grafting of 'Pala' onto 'Hawk' increased the thousand seed weight by 12.64% as well as by 8.05% in 'Topan' grafted onto 'Hawk', respectively (Figure 4). Similar results obtained by KOMBO and SARI (2019) in watermelon plants and ULAS (2019) in pepper plants who clearly stated that grafted plants produced more seed yield and also more thousand seed weight than non-grafted control plants. Enhanced seed yield in grafted plants may be the result of increased plant biomass and number and size of fruits,that were all caused by the consequences of a stronger and deeper root system that can absorb more water and nutrients.

CONCLUSIONS

The results of the present study reveal differences between scion/rootstock combinations for shoot and root fresh and dry biomasses, plant height, total leaf area, leaf chlorophyll index (SPAD), rootstock and scion stem diameter, number of fruits per plant, total fruit yield, fruit dry matter, fruit diameter and length, total seed yield, and thousand seed weight. The significantly higher plant growth, development, productivity, fructification and seed yield were presented with the graft combination 'Pala/Köksal F1', which coincided with the maximum yield of all scion/roostock combinations evaluated. For improving plant growth, total fruit and seed yield in eggplant plants, grafting can be used as a quick and effective method, which has advantageous suggestions for sustainability in agriculture.

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REFERENCES

ADAM, M.B. (2018): Genotypic differences in nitrogen efficiency and rootstock potential of some local Tomato varieties of Ghana and Turkey. Master Thesis (Unpublished). Erciyes University, Graduate School of Natural and Applied Sciences, Kayseri, Turkey, 109p.

AMIRI, E., A.A., GOHARI, Y., ESMAILIAN (2012): Effect of irrigation and nitrogen on yield, yield components and water use efficiency of eggplant. Afr. J. Biotech., *11*(13):3070-3079.

AYDIN, O. (2006): Effect of different grafting techniques on growth and development of rootstocks in pepper. Master Thesis (Unpublished). Gaziosmanpaşa University, (in Turkish).

BLACK, L., D., WU, J., WANG, T., KALB, D., ABBASS, J.H., CHEN (2003): Grafting Tomatoes for Production in the Hot-wet Season. Asian Vegetable Research and Development Center, Tainan, Taiwan. 6pp.

BLETSOS, F., C., THANASSOULOPOULOS, D., ROUPAKIAS (2003): Effect of grafting on growth, yield and *Verticillium* wilt of eggplant. Hort. Sci., *38*: 183–186.

BLETSOS, F., C.M., OLYMPIOS (2008): Rootstocks and grafting of tomatoes, peppers and eggplants for soil borne disease resistance, improved yield and quality. The Europ. J. Plant Sci. Biotech., *2*(1): 63-73.

COLLA, G., A., FIORILLO, M., CARDARELLI, Y., ROUPHAEL (2014): Grafting to improve abiotic stress tolerance of fruit vegetables. University of Tuscia, Viterbo, Italy. 7pp.

DAVIS, A.R, P., PERKINS-VEAZIE, R., HASSELL, A., LEVI, R., STEPHEN, S.R., KING, X., ZHANG (2008): Grafting effects on vegetable quality. Hort. Sci., *43*(6): 1670-1672.

DONAS-UCLES, F., M., JIMÉNEZ-LUNA, M., DEL, J.A., GÓNGORA-CORRAL, D., PÉREZ-MADRID, D., VERDE-FERNÁNDEZ, F., CAMACHO-FERRE (2014): Influence of three rootstocks on yield and commercial quality of Italian Sweet pepper. Ciência e Agrotecnologia, *38*: 538-545.

FAOSTAT PRODUCTION: Available online: www.fao.org (accessed on 16 april 2020).

GISBERT, C., P., SÁNCHEZ-TORRES, M.D., RAIGÓN, F., NUEZA (2010): *Phytophthora capsici* resistance evaluation in pepper hybrids: Agronomic performance and fruit quality of pepper grafted plants. J. Food Agr. Environ., *8*:116-121.

GISBERT, C., J., PROHENS, M.D., RAIGON, J.R., STOMMEL, F. NUEZ (2011): Eggplant relatives as sources of variation for developing new rootstocks: Effects of grafting on eggplant yield and fruit apparent quality and composition. Sci. Hortic., *128*: 14–22.

HANSON, P.M., R.Y., YANG, S.C.S., TSOU, D., LEDESMA, L., ENGLE, T.C., LEE (2006): Diversity in eggplant (*Solanum melongena*) for superoxide scavenging activity, total phenolics, and ascorbic acid. J. Food Compos. Anal., *19*:594–600.

HANACHI, S., M.C., LABEKE, T., MEHOUACHI (2014): Application of chlorophyll fluorescence to screen eggplant (*Solanum melongena* L.) cultivars for salt tolerance. Photosynthetica, *52*(1):57-62.

HOZA, M., M., DOLTU, M., DINU, A.D., ECHERESCU, A.I., APAHIDEAN, M.I., BOGOESCU (2017): Response of Different Grafted Eggplants in Protected Culture. Not. Bot. Horti. Agrobo, *45*(2):473-480.

JOHNSON, S., D., INGLIS, C., MILES (2014): Grafting Effects on Eggplant Growth, Yield, and *Verticillium* Wilt Incidence. Int. J. Vegetable Sci., *20*(*1*): 3-20.

KHAH, E.M. (2005): Effect of grafting on growth, performance and yield of aubergine (*Solanum melongena* L.) in the field and greenhouse. J.Food, Agric. Environ., *3*(3&4):92-94.

KHAH, E.M. (2011): Effect of grafting on growth, performance and yield of aubergine (*Solanum melongena* L.) in the field and greenhouse. Int. J. Plant Prod., *5*(4).

KHAN, R. (1979): *Solanum melongena* and its ancestral forms. In: Hawkes JC, Lester JG and Skelding AD (eds.), The biology and taxonomy of the Solanaceae, Linean Soc., Academic Press, London, 629–638.

KING, S.R., A.R., DAVIS, X., ZHANG, K., CROSBY (2010): Genetics, breeding and selection of rootstocks for Solanaceae and Cucurbitaceae. Scientia Horticulturae, *127*(2): 106-111.

KIRAN, S., F., OZKAY, S., KUSVURAN, S.S., ELLIALTIOGLU (2014): The Effect of Humic Acid application on some morphological, physiological and biochemical characteristics of eggplants irrigated with water contained heavy metals in high concentration. Turk. J. Agri. Food Sci. Technol., *2*(6):280-288.

KOMBO, M.D., N., SARI (2019): Rootstock effects on seed yield and quality in watermelon. Horticulture, Environment, and Biotechnology, *60*:303–312.

KUBOTA, C., M.A., MCLURE, N., KOKALIS-BURELLE, M.G., BAUSHER, N., ERIN, E.N., ROSSKOPF (2008): Vegetable grafting: History, use, and current technology status in North America. Hortic. Sci., *43*(6): 1664-1669.

LEE, J. M. (1994): Cultivation of grafted vegetables I: current status, grafting methods and benefits. Hort. Sci., *29*: 235–239.

LEE, J.M., M., ODA (2003): Grafting of herbaceous vegetable and ornamental crops. Hortic. Rev., *28*: 61-124.

LEE, J.M., C., KUBOTA, S.J., TSAO, Z., BIE, P., HOYOS ECHEVARRIA, L., MORRA, M., ODA (2010): Current status of vegetable grafting: diffusion, grafting techniques, automation. Scientia Horticulturae, *127*: 93-105.

MIGUEL, A., J.V., MAROTO, A., SAN BAUTISTA, C., BAIXAULI, V., CEBOLLA B., PASCUAL, S., LÓPEZ, J.L.. GUARDIOLA (2004): The grafting of triploid watermelon is an advantageous alternative to soil fumigation by methyl bromide for control of Fusarium wilt. Scientia Hort., *103*:9-17.

MOHAMED, F., K.E.A., EL-HAMED, M., ELWAN, M.A., HUSSIEN (2014): Evaluation of different grafting methods and rootstocks in watermelon grown in Egypt. Scientia Horticulturae, *168*:145–150.

MUDGE, K., J., JANICK, S., SCOFIELD, E.E., GOLDSCHMIDT (2009): A History of Grafting. Hortic. Rev., *35*: 437-493.

MUDGE, K., J., JULES, S., STEVEN, E.G., ELIEZER (2009): A History of Grafting, Horticultural Reviews, John Wiley & Sons, Inc. 2009, 35.

MUNOZ-FALCON, J.E., J., PROHENZ, A., RODRÍGUEZ-BURRUEZO, F., NUEZ (2008): Potential of local varieties and their hybrids for the improvement of eggplant production in the open field and greenhouse cultivation. J. Food Agric. Environ., *6*: 83–88.

NOTHMANN, J., I., RYLSKI, M., SPIGELMAN (1979): Flowering-pattern, fruit growth and color development of eggplant during the cool season in a subtropical climate. Sci. Hortic. *11*:217-222.

ODA, M. (1998): Grafting of Vegetables to Improve Greenhouse Production. Osaka Prefecture University, Sakai Osaka, Japan. 11pp.

OKA, Y., R., OFFENBACH, S., PIVONIA (2004): Pepper rootstock graft compatibility and response to *Meloidogyne javanica* and *M. incognita*. J. Nematol., *36(*2*):* 137–141.

PALADA, M.C., D.L., WU (2008): Evaluation of chili rootstocks for grafted sweet pepper production during the hot-wet and hot-dry seasons in Taiwan. Acta Horticulturae, *767*: 167-174.

PASSAM, H.C., M., STYLIANOU, A., KOTSIRAZ (2005): Performance of eggplant grafted on tomato and eggplant rootstocks. Eur. J. Hortic. Sci., *70*(30): 130-134.

PETRAN, A., E., HOOVER (2014): *Solanum torvum* as a compatible rootstock in interspecific tomato grafting. J. Hortic., *1*(1): 1-4.

PINA, P., P., ERREA (2005): A review of new advances in mechanism of graft compatibility-incompatibility. Scientia Hort., *106*:1-11.

PORTIS, E., L., BARCHI, L., TOPPINO, S., LANTERI, N., ACCIARRI, N., FELICIONI, F., FUSARI, V., BARBIERATO, F., CERICOLA, G., VALÈ, *et al*. (2014): QTL mapping in eggplant reveals clusters of yield-related loci and orthology with the tomato genome. PLoS ONE, *9*: e89499.

RIVERO, R.M., J.M., RUIZ, L., ROMERO (2003): Role of grafting in horticultural plants under stress conditions. Food, Agric. Environ., *1*(1): 70-74.

RODRIQUEZ, M.M., P.W., BOSLAND (2010): Grafting Capsicum to Tomato Rootstocks. The Journal of Young Investigators, *20*(2): 1-6.

ROUPHAEL, Y., M., CARDARELLI, A., BASSAL, C., LEONARDI, F., GIUFFRIDA, G., COLLA (2012): Vegetable quality as affected by genetic, agronomic and environmental factors. J. Food, Agric. Environ., *10* (3&4): 680-688.

SABATINO, L., G., IAPICHINO, F., D'ANNA, E., PALAZZOLO, G., MENNELLA, G.L., ROTINO (2018): Hybrids and allied species as potential rootstocks for eggplant: Effect of grafting on vigour, yield and overall fruit quality traits. Sci. Hortic., *228*: 81-90.

SABATINO, L., G., IAPICHINO, G.L., ROTINO, E., PALAZZOLO, G., MENNELLA, F., D'ANNA (2019): *Solanum aethiopicum* gr. *gilo* and Its Interspecific Hybrid with *S. melongena* as Alternative Rootstocks for Eggplant: Efects on Vigor, Yield, and Fruit Physicochemical Properties of Cultivar Scarlatti. Agronomy, *9*: 223.

SHAHBAZ, M., M., ASHRAF (2013): Improving salinity tolerance in cereals. Crit. Rev. Plant Sci., *32*:237–249.

SOLTAN MAHMOUD, M., A.F., ELAIDY, C.J., SCHEERENS, M.D., KLEINHENZ (2017): Grafting, Scion and Rootstock Effects on Survival Rate, Vegetative Growth and Fruit Yield of High Tunnel-grown Grafted Pepper (*Capsicum annuum* L.) Plants. Adv. Crop Sci. Techn., *5*: 312.

SUTERNO, H., S., DANIMIHARDJA, G.J.H., GRUBBEN (1993): *Solanum melongena* L. in: Plant Resources of South East Asia. No. 8. Vegetables. Siemonsma, J.S.; Piluek, K. (Eds.). Pudoc Scientific Publishers, Wageningen, The Netherlands. pp.255-258.

TSABALLA, A., C., ATHANASIADIS, K., PASENTSIS, I., GANOPOULOS, I., NIANIOU-OBEIDAT, A., TSAFTARIS (2013): A. Molecular studies of inheritable grafting induced changes in pepper (*Capsicum annuum*) fruit shape. Sci. Hortic., *149*: 2-8.

ULAS, A., E., DOGANCI, F., ULAS, H., YETISIR (2019): Root-growth characteristics contributing to genotypic variation in nitrogen efficiency of bottle gourd and rootstock potential for watermelon. Plants-Basel, *8*: 77.

ULAS, F. (2019): Effects of Rootstocks with Vigorous Root System on Plant Growth, Seed Yield and Quality of Pepper (*Capsicum annuum* L.) Inbred Lines. PhD Thesis (Unpublished). Erciyes University, Graduate School of Natural and Applied Sciences, Kayseri, Turkey, 228p, (in Turkish).

ULAS, F., A., AYDIN, A., ULAS, H., YETISIR (2019a): Grafting for sustainable growth performance of melon (Cucumis melo) under salt stressed hydroponic condition. Eur. J. Sust. Develop., *8*,1: 201-210.

ULAS, F., A., FRICKE, H., STUTZEL (2019b): Leaf physiological and root morphological parameters of grafted tomato plants under drought stress conditions. Fresenius Environmental Bulletin, *28*,4A: 3423-3434.

ULUKAPI, K., A.N., ONUS (2005): Effect of grafted seedlings on F1 191 tomato genotype regarding yield, and quality properties. Akdeniz University Agriculture Faculty, GAP IV. Agriculture Congress, 1314-1317 p, Şanlıurfa. (in Turkish).

WANG, S., R., YANG, J., CHENG, J., ZHAO (2007): Effect of rootstocks on the tolerance to high temperature of eggplants under solar greenhouse during summer season. Acta Hortic., *761*: 357-360.

YETISIR, H., N., SARI (2019): Effects of bottle gourd (*Lagenaria siceraria*) rootstocks on plant nutrient content of watermelon [*Citrullus lanatus* (Thunb.) Mats. & Nak.] leaf and nitrogen use efficiency. Derim, *36*(1):24-32.

YÜCEL, Y.C. (2020): Agronomical, Physiological and Morphological Characterization of Some Selected Eggplant (*Solanum melongena* L.) Genotypes for Nitrogen Efficiency and Rootstock Potential. Master Thesis (Unpublished). Erciyes University, Graduate School of Natural and Applied Sciences, Kayseri, Turkey, 186p, (in Turkish).

UTICAJ RAZLIČITIH PODLOGA NA VEGETATIVNI RAST, PRINOS PLODA I SEMENA PATLIDŽANA (*Solanum melongena* L.)

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Izvod

U ovoj studiji, različiti genotipovi potomaka patlidžana su kalemljeni na različite genotipove podloge patlidžana kako bi se procenili rast, razvoj i prinos plodova biljaka patlidžana na osnovu mehanizama fizioloških i morfoloških odgovora. Eksperiment je izveden na terenu za istraživanje povrća u kampusu na Poljoprivrednom fakultetu Univerziteta Erciies, Kaiseri-Turska. Eksperiment u polju je sproveden za određivanje rasta biljaka, izdanaka i korena svežih i suvih biomasa, visine biljke, ukupne površine lista, indeksa hlorofila lista (SPAD), prečnika stabljike podloge i potomka, broja plodova po biljci, ukupnog prinosa ploda, suve materije ploda, prečnika i dužine ploda, ukupnog prinosa semena i težine hiljadu semena. Dve sorte patlidžana („Topan“ i „Pala“) kalemljene su na dva različita genotipa podloge patlidžana („Hawk“ i „Köksal F1“), dok su kao kontrolne biljke korišćeni nekalemljeni genotipovi potomaka. Eksperiment je postavljen u potpuno randomiziranom blok dizajnu (RCBD) koji je imao tri ponavljanja. Rezultati su pokazali da su između kalemljenih i nekalemljenih biljaka uočene značajne (P <0,001) razlike u svežim i suvim biomasama izdanaka i korena, visini biljke, ukupnoj površini lista, indeksu hlorofila lista (SPAD), prečniku matičnjaka i stabla potomka, broju plodova po biljci, ukupnom prinosu ploda, suvoj materiji ploda, prečniku i dužini ploda, ukupnom prinosu semena i težini hiljadu semena. Korišćene podloge uticale su na snagu kalemljenih biljaka. „Pala“ kalemljena na podlogu „Köksal F1“ registrovala je prirast od 61,91% u svežoj biomasi izdanaka i 49,04% prirast u svežoj biomasi korena u poređenju sa neklemljenim biljkama. Kalemljenje je uticalo na visinu biljke koja je dostigla vrednosti od približno 1,0 m, površina lista rezultirala je vrednostima od 5645,04 cm2 biljka-1, a SPAD rezultirao vrednostima od 47,48 na kombinaciji kalemljenja „Pala / Köksal F1“ u poređenju sa neklemljenim biljkama. Kombinacije kalemljenja takođe su uticale na produktivnost biljaka u poređenju sa nekalemljenim biljkama. Značajno najveći prinos ploda dobijen je iz kombinacije kalem „Pala / Köksal F1“ i bio je od 4711,89 g biljke-1, zatim kombinacije kalem „Topan / Köksal F1“ sa 3834,54 g biljke-1. „Pala“ je dala 11,49 plodova po biljci kada je kalemljena na podlogu ’Köksal F1’ i 8,46 plodova po biljci kada je kalemljena na podlogu „Hawk“. Što se tiče prinosa semena, „Pala“ kalemljena na podlogu „Köksal F1“ zabeležila je rast od 72,03% u ukupnom prinosu semena u poređenju sa neklemljenim biljkama. Sve u svemu, genotipovi podloge patlidžana „Köksal F1“ pokazali su bolje performanse izdanaka i korena, sveže i suve biomase, visine biljke, ukupne površine lista, indeksa hlorofila lista (SPAD), prečnika stabljike podloge i potomka, broja plodova po biljci, ukupni prinos ploda, suve materije ploda, prečnika i dužine ploda, ukupnog prinosa semena i mase hiljadu semena u poređenju sa nekalemljenim biljkama.

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