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Fruit and Seed Yields of Watermelon [*Citrullus lanatus* (Thunb.) Matsum. and Nakai] Grafted onto Different Bottle Gourd (*Lagenarai siceraria* Molina Standl.) Rootstocks

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Authors' contribution

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

In this study, the effect of rootstock on seed yield of watermelon was investigated. The watermelon [C*itrullus lanatus* (Thunb.) Matsum and Nakai] cultivar Crimson Tide was grown three successive years by grafting onto *Lagenaria* type rootstocks to investigate rootstocks effects on seed yield. Skopje, Emphasis, 216 and FRG (hybrid) and Birecik (landraces) were used as rootstock and ungrafted Crimson Tide watermelon cultivar was used as the control. The study was conducted in research area of Department of Horticulture, Faculty of Agriculture, University of Cukurova located in Cukurova region, Southern Turkey, where watermelon cultivation is conducted mostly under low tunnels for early production. Plants were grafted by hole insertion grafting method and grown under low tunnel conditions until the outdoor temperature was suitable (22-25ºC) for watermelon production. Fruit yield, seed number/kg fruit flesh, seed number per fruit and unit area were significantly affected by rootstocks and the grafted plants produced higher seed yield than the ungrafted control plants regardless of growing year. Rootstocks with vigorous root system caused increased seed yield by promoting plant growth, fruit number and fruit size in grafted watermelon.

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1. INTRODUCTION

Watermelon is o ne of the most grown vegetable crops in Turkey. Turkey is the world's second largest watermelon producing country after China with about 4 million tons [1]. In the Cukurova region, southern Turkey, watermelon cultivation is conducted mostly under low tunnels for early production. Watermelon has been cultivated intensively for many years in this region. One of the serious problems of the watermelon production in Çukurova region is a yield loss due to soil-borne diseases, in particular *Fusarium*, and successive cropping. Grafting onto suitable rootstocks is an efficient way to overcome this problem in watermelon production [2,3].

Grafted in fruit bearing vegetables started about 100 years ego in Korea and Japan [4]. The primary objective of the grafting in vegetables was to protect plants from soil-borne diseases such as *Fusarium* and *Verticillium*. After successful application of the interspecific grafting watermelon by grafting on gourd rootstocks, grafting purposes and grafted species in vegetable crops has been significantly increased [2]. Researches on cucumber grafting (*C. sativus* L.) also were introduced at the same time with watermelon grafting in the late 1920s, but widely agricultural applications occurred after 1960 [5]. In the *Solanaceaous* species, the earliest grafting practice was in eggplant (*Solanum melongena* L.) by grafting on *S. integrifolium* Poir (scarlet eggplant) in the 1950s [6]. Tomato (*S. lycopersicum* L.) has been commercially grafted since 1960s [7]. At present, grafted plants are used for mostly watermelon, tomato, eggplant, cucumber, melon and pepper in both open field and protected cultivation in Japan and Korea as well as other Asian and European countries such as China, Spain, Italy, Greece, Turkey and Israel, where fruit-bearing vegetables are being cultivated intensively [8,2,9]. Commercial grafting in vegetable crops was originated from Japan and Korea and was commercially used for more than 50 years. Some European countries introduced it in the early 1990s and it is currently being common horticultural application using local/introduced scion varieties and imported rootstocks in *Cucurbitaceous* and *Solanaceous* crops.

The ban of methyl bromide (MB) fumigation has led to researches on alternative control methods for soil-borne pathogen in vegetable production, particularly in greenhouse and plastic tunnel vegetable cultivation. Although alternative chemical applications and other cultural practices have been tested and developed, one of the best environmentally friendly strategies to overcome soil-borne diseases problem is grafting susceptible cultivars onto resistant rootstocks. Furthermore, plant growth parameters, flowering, fruit ripening time, yield, and quality are improved by grafting onto suitable rootstocks [3].

Common objectives of the grafting in vegetables are tolerance to high [10] and low [11] temperatures, to iron deficiency in high pH soils conditions [12], to saline soil conditions [13], to promote plant nutrition absorption [14] and to increase water uptake and use efficiency [15]. Watermelon can be grafted onto interspecific squash hybrids (*Cucurbita maxima* Duch. × *C.moschata* Duch.), calabash (*L. siceraria* L.), squash (*C. moschata* Duch.) pumpkin (*C. pepo* L.), *Benincasa hispida* Thunb., watermelon [*Citrullus lanatus* (Thunb.) Matsum. et Nakai], African horned cucumber (*Cucumis metuliferus* E. Mey. Ex Naud) [16], sponge gourds (*Luffa* spp.*)* [2,17]), and wild watermelon (*Citrullus lanatus* var. *citroides*) [18] for different objectives. Commercial grafted watermelon production is widely practiced by grafting onto hybrid squash and bottle gourd rootstocks [16].

The higher plant growth and yield due to grafting onto suitable rootstocks have been reported earlier in watermelon [3,19,20], melon [1214] , cucumber [21,22], tomato [23], eggplant [24,25] and pepper [26,27]. Promoting effect of the grafting onto plant growth and yield can be attributed to the interaction of some or all of the following physiological activities: improved water and plant nutrient absorption due to the rootstock's strong root system [2,14], increased production of phytohormones [28,29], protective effect of rootstocks against some biotic and abiotic stresses [13,30,31,32] and promotion of scion vigor [33]. Studies on grafting in fruit bearing vegetables have been focused on mainly yield and quality [16,34], tolerance to abiotic stressful conditions [13,31,32], disease resistance [30,35,36] but studies about effect of grafting on different rootstocks on seed production is quite limited [2]. Grafting on suitable rootstocks enhanced plant growth and yield due to reasons mentioned above. It can be speculated that since grafting of scions on suitable rootstocks supports plants different aspects to produce higher fruit yield, it can be utilized in seed production especially under problematic conditions. Therefore, in this study rootstocks effect of different bottle gourd rootstocks on seed and fruit yield of watermelon cultivar Crimson Tide was investigated.

2. MATERIALS AND METHODS

2.1 Production of Grafted Watermelon Seedlings and Experimental Design

The watermelon [*Citrullus lanatus* (Thunb.) Matsum. and Nakai] cultivar Crimson Tide was grafted onto 5 different bottle (*Lagenaria siceraria*) gourd rootstocks (Table 1). Crimson Tide watermelon cv. is suitable for main and mid-early growing seasons for both open field and protected cultivation. Fruit set is powerful and high yielding variety. It has distinctive smoky skin pattern and very long shelf life. Seeds of scion cultivar were sown one week before than rootstocks seeds. The hole-insertion grafting technique was used and plants were grafted following the procedure described by Lee (1994) and [7] (Fig. 1). Ungrafted Crimson Tide seedling were used as control. Seedlings were grown in an unheated greenhouse under plastic tunnels. The grafted seedlings produced in the greenhouse were transplanted under low tunnels, and the tunnels were removed when the outside air temperature was suitable (20-25°C) for watermelon cultivation. Seedlings were transplanted with 2.0 by 0.5 m spacing. Plants were fertilized with 180 kg N/ha, 200 kg P_2O_5/ha and 180 kg K_2O/ha. Total P was applied before transplanting to the field. Nitrogen and K_2O were divided into 3 equal portions. The first portion was applied before transplanting to the field, the second 20 days after transplanting and the third 40 days after transplanting in the field. The experimental design was a completely randomized block design. Each treatment was replicated 4 times with 15 plants in each replicate. The study was conducted in research area of Department of Horticulture, Faculty of Agriculture, University of Çukurova which is located at 37°01'48.23'' N latitude, 35° 22'02.59'' E longitude and elevation above sea level is 55 m.

2.2 Harvest and Measurements

Ripe fruits were harvested twice and weighed immediately after harvest for fruit weight (g) and total yield (ton/ha and g/plant). The selected five fruit from each replicate were sliced and seeds were counted for each weighted fruit. Seed number per fruit and seed yield (number/kg flesh, number/m^2 and seed number per plant) were determined.

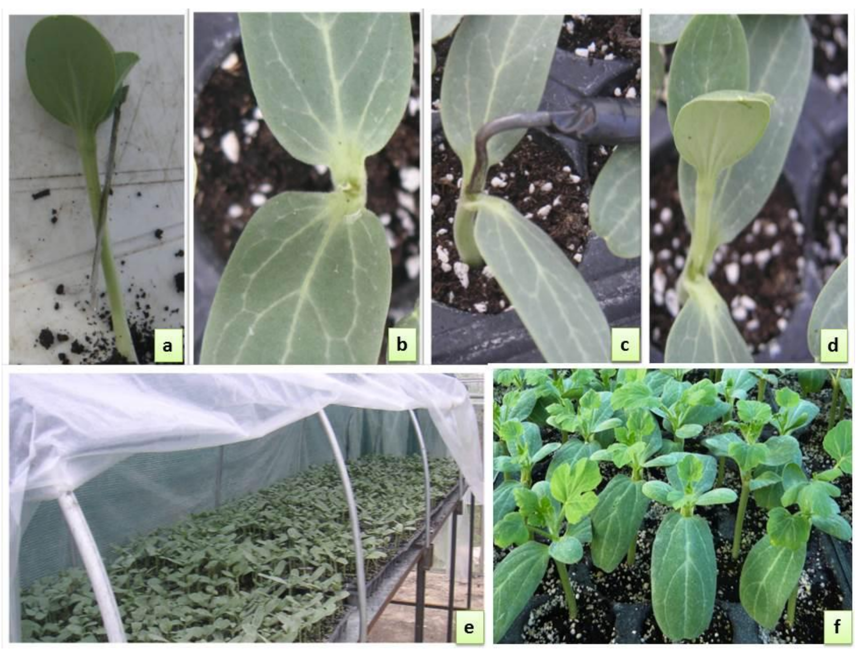

Fig. 1. Hole Insertion Grafting method. a: Scion preparation, b: Rootstock preparation, c: Hole formation, d: Insertion of scion, e: Post graft care unit, f: Grafted seedling ready for transplanting

Table 1. Name, definition, resistance and origin of rootstocks

Rootstocks	Definition	Resistance	Origin
216*	*Lagenaria siceraria* hybrid	*Fon* 0, 1, 2	Korea
FR Gold	*Lagenaria siceraria* hybrid	*Fon* 0, 1, 2	Korea
Emphasis	*Lagenaria siceraria* hybrid	*Fon* 0, 1, 2	Korea
Skopje	*Lagenaria siceraria* hybrid	*Fon* 0, 1, 2	Korea
Birecik	*Lagenaria siceraria* landraces	*Fon* 0, 1, 2	Turkey- Sanlıurfa

**: 216 was used in the third experiment due to unavailability of the seed. Fon: Fusarium oxysporum f. sp. niveum*

2.3 Statistical Analysis

Data were subjected to an analysis of variance using SAS software [37] SAS statistical program and mean separation was performed with Tukey's test at P<0.01 and P<0.05 levels and LSD values are also presented.

3. RESULTS AND DISCUSSION

3.1 First Experiment

Fruit yield was significantly affected by rootstocks and all of the graft combinations produced higher yield than the ungrafted control plants. The highest yield was harvested from CT/Skopje graft combination with 118.8 ton/ha and 11880 g/plant while lowest yield was taken from the ungrafted control plants with 59.7 ton/ha and 7973 g/plant in the first year of the experiment. Fruit weight was also positively influenced by grafting onto different rootstocks and the grafted plants had larger fruits than the ungrafted control plants. As in yield, the heaviest fruit was harvest from CT/Skopje graft combination whereas the ungrafted control plants produced smallest fruits with 4018 g. Other graft combinations produced similar fruit weight with CT/Skopje graft combination (Table 2).

Seed yield for kg fruit weight significantly varied based on rootstocks. The highest seed yield was recorded in the ungrafted control plants and CT/216 graft combination which have the smallest fruit while other four graft combinations had lower seed number for kg fruit weight in the first year of the experiment. Seed number per fruit was also significantly increased by grafting. Seed number per fruit varied from 556.1 seed/fruit (ungrafted control) to 858.8 seed/fruit (CT/216). Seed yield for unit area was also significantly affected by rootstocks and higher seed yield was recorded in all the grafted plants. While lowest seed yield was harvested from the ungrafted control plants with 33.3 g/m^2, CT/Skopje graft combination produced the highest yield with 59.2 g/m^2. Rootstocks had significant effects on seed number per plants and grafting onto different rootstocks increased significantly seed number per plants. While lowest seed number per plants was determined in the ungrafted control plants, the highest number per plant was recorded in CT/Skopje graft combination with 1479 see per plant (Table 2).

3.2 Second Experiment

Total yield was significantly affected by rootstocks genotypes, and all the grafted plants produce higher yield than the ungrafted control plants. CT/Birecik and CT/Skopje graft combinations had the highest yield while lowest yield was harvested from the ungrafted control plants with 68.4 ton/ha. Similar results were determined as regarded to fruit yield per plant. As in yield data, all the grafted plants produced larger fruits than the control plants. The largest fruits were harvested from CT/Skopje, CT/216 and CT/Birecik graft combinations whereas the smallest fruits were harvested from the ungrafted control plants with 5435 g (Table 3).

Seed yield results were presented in Table 3. Seed yield was significantly increased by grafting onto different rootstocks. The highest seed yield for kg fruit weight was recorded in the ungrafted control plants while the lowest seed yield for kg fruit weight was recorded in all the graft combinations except for CT/Emphasis combinations. Seed yield per fruit varied from 489 seed per fruit to 739 seed per fruit. The highest seed number per fruit was determined in CT/Skopje and CT/216 graft combinations with 739 and 719, respectively whereas the lowest seed number per fruit was determined in the ungrafted control plants with 489 seed per fruit.. As in other seed yield parameters, rootstock effect of on seed yield for m^2 was found significant. While the highest seed yield was recorded in CT/Birecik and CT/Skopje combinations with 1385 and 1448 seed/m^2, respectively the lowest seed yield was recorded in the ungrafted control plants, CT/216, CT/FR Gold graft combinations. Rootstocks effect on seed number per plants was found significant and grafting onto different rootstocks had positive effect on seed number per plant. Seed number per plant varied from 768 (ungrafted control plants) to 1448 (CT/Skopje).

Table 2. Fruit and seed yield of grafted watermelon onto different bottle gourd rootstocks in the first year of the experiment

Scion / rootstock	Fruit yield (ton/ha)	Fruit yield (g/plant)	Fruit weight (g)	Seed yield (number/kg fruit)	Seed number per fruit	Seed yield (g/m^2)	Seed number per plant
CT[1]	59.7 e[2]	5973 e	4018 c	139.0 a	556.1 c	33.3 d	832 d
CT/216	79.3 d	7928 d	5996 b	143.5 a	858.8 a	45.5 b	1137 b
CT/FR Gold	83.5 c	8348 c	6894 a	115.0 b	793.6 ab	38.4 c	959 c
CT/Emphasis	81.6 cd	8163 cd	6390 ab	118.0 b	753.6 b	38.4 c	960 c
CT/Birecik	91.8 b	9180 b	6255 ab	120.0 b	750.3 b	43.9 b	1099 b
CT/Skopje	118.8 a	11880 a	6764 a	124.5 b	841.6 ab	59.2 a	1479 a
LSD	4.02 ***	402.6 ***	689.6 ***	10.9 ***	100.1 ***	3.9 ***	99.3 ***

*1: CT: Crimson Tide; 2: Means with the same letter are not significantly different from each other (P>0.05). ***: Significant at 0.001*

Table 3. Fruit and seed yield of grafted watermelon onto different bottle gourd rootstocks in second year of the experiment

Scion / rootstock	Fruit yield (ton/ha)	Fruit yield (g/plant)	Fruit weight (g)	Seed yield (number/kg)	Seed number per fruit	Seed yield (g/m^2)	Seed number per plant
CT[1]	68.4 d[2]	6843 d	5435 d	114.8 a	489.2 d	31.4 c	768 c
CT/216	83.7 c	8373 c	7988 ab	95.0 c	718.9 ab	31.8 c	797 c
CT/FR Gold	89.6 c	8958 c	6881 bc	98.0 c	619.3 bc	35.1 c	878 c
CT/Emphasis	109.5 b	10948 b	6550 cd	107.0 b	589.5 cd	46.8 b	1170 b
CT/Birecik	136.9 a	13688 a	7518 abc	101.3 bc	676.6 abc	55.4 a	1385 a
CT/Skopje	146.4 a	14638 a	8207a	99.0 c	738.6 a	57.9 a	1448 a
LSD	10.4 ***	1040 ***	1276 ***	7.63 ***	114.9 ***	5.3 ***	132.6 ***

*1: CT: Crimson Tide; 2: Means with the same letter are not significantly different from each other (P>0.05). ***: Significant at 0.001*

Table 4. Fruit and seed yield of grafted watermelon onto different bottle gourd rootstocks in third year of the experiment

Scion/ rootstock	Fruit yield (ton/ha)	Fruit yield (g/plant)	Fruit weight (g)	Seed yield (number/kg flesh)	Seed number per fruit	Seed yield (g/m^2)	Seed number per plant
CT[1]	54.1 d[2]	9640 d	6667 b	75.6	502.7 b	16.4 c	730 c
CT/Emphasis	98.1 c	18327 c	8625 a	69.8	602.4 ab	27.4 b	1281 b
CT/Birecik	138.0 a	24843 a	8126 a	79.8	648.2 a	44.2 a	1989 a
CT/Skopje	127.9 b	23017 b	9087a	68.4	621.3 a	35.0 b	1574 b
LSD	6.52 **	1585 **	1260 *	12.1 n.s.	103.2 *	8.2 **	385 **

*1: CT: Crimson Tide; 2: Means with the same letter are not significantly different from each other (P>0.05). ***: Significant at 0.001*

3.3 Third Experiment

As in first and second experiments, fruit yield was significantly affected by rootstocks and all of the graft combinations produced significantly higher yield than the control plants. The highest total fruit yield was recorded in CT/Birecik graft combination with 138 ton/ha whereas the lowest total fruit yield was harvested from the ungrafted control plants with 54.1 ton/ha. Yield increase due to grafting onto different rootstocks compared to control ranged from 81% to 155%. Fruit yield per plant showed the same trend with total yield. Fruit weight was also affected by rootstocks and the grafted plants produced from 21% to 31% bigger fruit than the ungrafted control plants (Table 4).

Seed number per kg fruit weight was not affected by rootstocks in the third experiment but seed number per fruit was significantly influenced by rootstocks. Higher seed number per fruit was recorded in the grafted plants compared to the control plants. The highest number of seed per fruit was determined in the plants grafted onto Skopje and Birecik rootstocks while the ungrafted control plants had the lowest number of seed per fruit in third experiment. Seed yield for unit area was also significantly affected by rootstocks and all the grafted plants produced higher seed yield than the ungrafted control plants. The highest seed yield was produced by CT/Birecik graft combination with 44.2 g/m^2 and it was followed by CT/Skopje and CT/Emphasis while the ungrafted control plants had the lowest seed yield with 16.4 g/m^2. Seed yield per plant was significantly affected by rootstocks and showed similar trend with seed yield for unit area (Table 4).

Fruit yield and seed yield were significantly affected by rootstocks and all the graft combinations produced higher fruit and seed yield than the control plants. Significant positive correlation was found between total seed yield with total fruit yield (r=0.9), fruit weight (r=58) and seed yield per fruit (r=0.72) whereas meaningful relation between total seed yield and seed number per kg fruit weight was not determined.

Fruit yield in watermelon is a function of fruit size and fruit number: generally, intensive planting increases fruit number per growth area and decreases single fruit weight. Several previous studies reported the relationship between plant density and fruit yield and fruit weight in watermelon [38,39,40,41]. In general, increasing plant density causes a yield increase per growth is for most plant species up to some threshold plant density for the species, after this critical threshold plants density further increase in plant density either sustain the same yield or cause decrease in yield [42]. Kavut et al. [43] reported that the number of fruit per plants increased by decreasing plant densities but not single fruit weight due to suitable source and sink relations on plants. The well-known phenomena that increased the rate of competitions between fruits may cause lower fruit weight size when produced photosynthetic assimilates in leaves is limited. In watermelon, total yield can be increased both by increasing fruit size and fruit number per unit area. In our study, total fruit yield, the yield for per plant and fruit weight were significantly influenced by rootstocks, and the grafted plants had higher values as regarded to mentioned yield components. Fruit number per plants was also increased by grafting onto different rootstocks. In agreement with our results, increase in total yield and fruit size at different levels was reported based on rootstocks and cultivation conditions in previous studies with the grafted watermelon [3,20,44,45,46,47]. The enhanced yield and fruit size in the grafted watermelon was attributed to vigorous and healthy plant growth provided by resistance to soil-borne disease [29,30,45], adverse soil conditions [10,15,14,48], promoted water and plant nutrient uptake [48] and high level of phytohormone production capacity of roots [49,50].

The seed yield consists of seed number per fruit, number of plant for unit area and average seed weight. Total seed yield is multiplication of these three components [41]. In this study, number of fruit per unit area and average fruit size were significantly increased by rootstocks and all the combinations had significantly higher seed yield than the ungrafted control plants in all three experiments. In three experiments, seed yield in control treatments varied from 16 g/m^2 to 33.3 g/m^2 whereas yield of the grafted plants ranged from 27.4 g/m^2 to 59.2 g/m^2. Mean seed yield increase in three experimental years varied from 28% to 112% compared to the control plants. Whener [51] stated that diploid open-pollinated seed yields in watermelon should be higher than 250 kg/ha and 400-450 kg/ha seed yields would be very good seed yield. In our experiment, all the graft combinations produced higher seed yield than commercially acceptable level (250 kg/ha). In agreement with Edelstein and Nerson [41], total seed yield was positively correlated with total fruit yield, fruit number per unit area and fruit size. As mentioned above, increased fruit yield, fruit number and fruit size were reported previously in grafted watermelon. The grafted watermelon plants onto rootstocks with vigorous root system providing adequate water and plant nutrition can produce stronger plants and increased photosynthetic assimilates due to larger leaf area and extended growing period [3,19,20]. Regular flowering, fruit setting and fruit development are key physiological processes for fruit-bearing vegetables. The plant can produce the highest yield within their genetic border as long as optimal environmental conditions, plant nutritions and water are provided. In this experiment, total seed yield in grafted plants was found higher than the ugrafted control plants due to advantages of rootstocks over the control plants.

4. CONCLUSION

Data of the current study showed that grafting watermelon onto suitable rootstocks significantly increase seed yield. It may be concluded that seed yield was increased by higher number and larger size of the fruits in the grafted plants. The most suitable combinations for total fruit and seed yield were CT/Birecik and CT/Skopje. Positive effects of the grafting onto suitable rootstocks on plant health, plant growth and yield were reported in previous studies. In commercial either open pollinated and hybrid seed production, seed yield for unit area and for labor used are very important. As shown in this study, vigorous and healthy plants had higher seed yield with high quality. Use of suitable rootstocks may provide probabilities for seed production in disease infested soils (open field or greenhouse) when plant rotation possibilities are limited. In hybrid seed production, weak and disease susceptible parental lines can be grafted to overcome weakness and disease susceptibility problems. Further studies should be carried out on effects of rootstocks on seed quality parameters in grafted vegetables.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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