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Rootstock capacity in improving production and quality of triploid watermelon seeds

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Abstract: The aim of this study was to evaluate different rootstocks for improving triploid seed production of the dessert watermelon, *Citrullus lanatus*. This 2-year study was conducted at two locations, in open fields at Antalya and Adana, Turkey, during the 2016 and 2017 growing seasons. The tetraploid watermelon line 'ST 101' was used as the female parent scion and the diploid line 'WL 92' as the male parent. Both parental lines were grafted onto three different rootstocks to determine the effect of grafting on seed yield and quality of triploid watermelon. Nun 9075, a *Cucurbita* interspecific hybrid (*Cucurbita maxima* × *Cucurbita moschata*), Argentario (*Lagenaria siceraria*), and citron watermelon PI 296341 (*Citrullus amarus*) were used as rootstocks. Nongrafted ST 101 and WL 92 were also crossed to be used as controls. The graft combinations and controls were compared for performance as measured by length, diameter and number of nodes of main stem, total yield, mean fruit weight, fruit length, fruit diameter, seed yield, number of seed per fruit, weight of 1000 seeds, seed germination and emergence percentage, days to germination and emergence, and seed coat and embryo weight ratio. Nun 9075/ST 101 and Argentario/ST 101 graft combinations resulted in longer main stems; increased total yield; heavier, longer, and wider fruits; and higher seed yield and number of seeds per fruit as compared to PI 296341/ST 101 graft combination and the controls in both locations and years.

Key words: Graft combinations, seed germination, seed emergence, tetraploid, yield

1. Introduction

The dessert watermelon, *Citrullus lanatus* (Thunb.) Matsum & Nakai, is a widely produced vegetable crop, grown mostly in open fields with traditional production techniques.

Seedless watermelons are produced by triploid plants obtained by pollinating a tetraploid female parent with pollen from a diploid male parent. To obtain tetraploids, the chromosomes of diploid female parent are duplicated by using colchicine (Inan and Sari, 2010; Kombo et al., 2016), oryzalin (Zhang, 2004; Şimsek et al., 2013), or trifluralin (Wei and Jang, 2006). Seedless watermelons have become highly popular and are preferred by consumers, mainly because of easier consumption of watermelon flesh free of hard seeds (Khereba et al., 2008).

Triploid watermelon seeds are difficult to germinate because triploid embryos are fairly weak in comparison with the thick seed coat inherited from the maternal tetraploid parent (Phat et al., 2015). Triploid seeds are also quite expensive to produce in comparison with diploids (Khereba et al., 2008). Good triploid seed production is of paramount importance for economical triploid fruit production (Motsenbocker and Arancibia, 2002). As the number of triploid seeds produced in tetraploid fruit is low compared with diploid fruit, it is important to find a more economical way to increase the number and quality of triploid seeds. As grafting increases watermelon fruit yield and quality, it may be possible to improve the yield and quality of triploid seeds by grafting their parent lines.

Several studies reported that grafting improves yield and fruit quality such as color, texture, flavor, and aroma (Yetişir and Sari, 2003; Davis et al., 2008a, 2008b; Turhan et al., 2012; Edelstein et al., 2014; Elazar et al., 2016; Fredes et al., 2016; Kyriacou et al., 2017). Grafting has been used to control root-knot nematodes (Lee et al., 2010; Thies et al., 2010, 2015) as well as soil-borne pathogens (Yetişir et al., 2003, 2007; Keinath and Hassell, 2014). Grafting often enhances plant vigor (Yetişir et al., 2003, Davis et al., 2008a, 2008b; Karaca et al., 2012; Petropoulos et al., 2014), extends harvesting period and prolongs postharvest life (Lee et al., 2010; Zhao et al., 2011; Kyriacou and Soteriou, 2015; Kyriacou et al., 2016), and improves drought tolerance, salt tolerance resistance, and water use efficiency (Yetişir and Uygur, 2010; Kumar et al., 2017). Grafting also improves fruit quality traits such as TSS, flesh firmness (Cushman and Huan, 2008), and texture (Liu et al., 2016) of seedless

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watermelons. However, the effects of grafting on seed yield and quality have not been examined in triploid or even in diploid watermelons to date. The objective of the present study was to determine if triploid seed yield and quality could be improved by grafting.

2. Materials and methods

A 2-year study was conducted in an open field of Antalya Tarım Productive, Consultant and Marketing Co. at Yanköy, Serik, Antalya, Turkey (36°59′44.6″N, longitude 31°00′09.5″E, altitude 244 m) and in an open field of the Department of Horticulture of Çukurova University at Sarıçam, Adana, Turkey (latitude 37°1′48.63″N, longitude 35°22′3.74″E, altitude 56 m) during 2016 and 2017. Both experimental locations are in the Mediterranean region and have a climate that is mild in winter and hot and humid in summer. During the growing period the mean air temperature was 22° C and 22.7° C in Antalya and 23.5° C in Adana in 2016 and 2017, respectively. Relative humidity was 68% and 63.4% in Antalya and 65.2% and 66% in Adana in 2016 and 2017. There was limited rainfall of 67.8 mm and 87.1 mm in Antalya and 158.6 mm and 126.2 mm in Adana in 2016 and 2017, respectively (Turkish State Meteorological Service, 2016, 2017).

2.1. Plant material

Three rootstocks, i.e. 'Nun 9075' the *Cucurbita* interspecific hybrid rootstock (*Cucurbita maxima* Duchesne × *Cucurbita moschata* Duchesne), which is widely used for grafting watermelons in Turkey; the bottle gourd 'Argentario' (*Lagenaria siceraria* (Mol.) Standl.; and the citron watermelon 'PI 296341' (*Citrullus amarus* Schrad.), which have high grafting combination ability and high resistance to *Fusarium*, were used as rootstocks. Seeds of PI 296341 were obtained from the watermelon genetic resources collection of the Department of Horticulture, Çukurova University, and the others were obtained from the Antalya Tarım Company.

Two dessert watermelon lines, *Citrullus lanatus*, were used as scions; the tetraploid 'ST 101' was used as the female parent and the diploid 'WL 92' as the male parent. Tetraploid 'ST 101' has round and striped fruits with red flesh and thick dark brown seeds while diploid 'WL 92' has ovate and striped fruits with red flesh and black seeds (Figure 1). All rootstocks were grafted with ST 101 and WL 92 scions, and therefore the following graft combinations were obtained: Nun 9075/ST 101 (tetraploid female parent), Nun 9075/WL 92 (diploid male parent), Argentario/ST 101 (tetraploid female parent), Argentario/WL 92 (diploid male parent), PI 296341/ST 101 (tetraploid female parent), and PI 296341/WL 92 (diploid male parent). Nongrafted ST 101 (tetraploid female parent) and nongrafted WL 92 (diploid male parent) were used for comparison (Table 1). At least 200 grafts were produced in each graft combination.

2.2. Seed sowing, grafting and transplanting

Seed sowing, grafting, and management practices of the grafted seedlings were done at the nursery of Antalya Tarım Productive, Consultant and Marketing Co. in

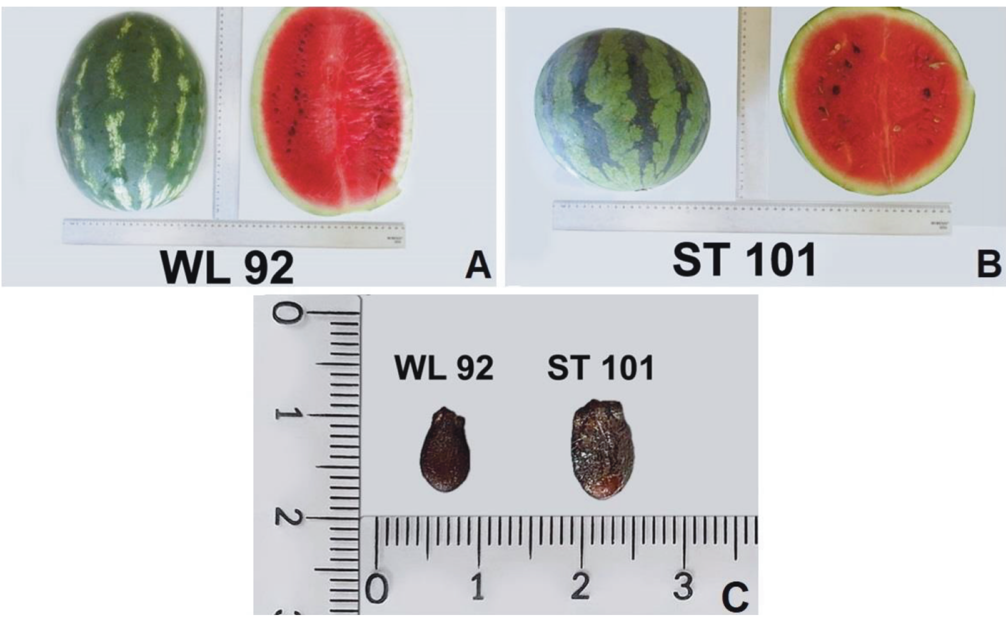

Figure 1. A) Diploid male parent WL 92; B) tetraploid female parent ST 101; C) seeds of diploid WL 92 and tetraploid ST 101.

Table 1. Graft combinations used in the experiments.

ST 101 (Tetraploid female parent scion)	WL 92 (Diploid male parent scion)
Argentario/ST 101	Argentario/WL 92
Nun 9075/ST 101	Nun 9075/WL 92
PI 296341/ST 101	PI 296341/WL 92
Control - ST 101 (Nongrafted)	Control - WL 92 (Nongrafted)

Antalya. Seeds were sown on 26 January 2016 and grafting was done on 23 February 2016. Seed sowing and grafting practices for year 2017 were performed on 3 February 2017 and 22 February 2017, respectively. Grafting was done according to the one cotyledon method described by Hassell et al. (2008). Seedlings were transplanted to the open field in Adana on 30 March 2016 and on 31 March 2016 in Antalya for 2016. All seedlings were transplanted on 7 April 2017 for both locations in 2017. Grafted and control (nongrafted) plants were transplanted at a spacing of 3 m × 0.75 m. In every plot 16 plants grafted with female parent scion of tetraploid ST 101 followed by 4 plants grafted with male parent scion (WL 92) were planted in four replications in a randomized block design. Soon after transplanted plants were covered with a lower plastic tunnel to protect from cold weather and heavy rain, holes in the plastic tunnels were made to allow air exchange and the tunnels were completely removed after 3 weeks. Drip irrigation was applied twice a week with polyethylene drippers having 20-cm intervals; frequency of watering was reduced at fruit maturity and stopped 2 weeks before harvesting. Fertilizer was applied at a rate of 180 kg N ha^{-1}, 200 kg ha^{-1} P_2O_5, and 180 kg ha^{-1} K_2O (Yetişir and Sari, 2003). Weeds, insect pests, and diseases were regularly controlled whenever the signs of presence were observed.

2.3. Pollination

Female flowers of tetraploid 'ST 101' line and male flowers of diploid 'WL 92' line for each graft combination and control were closed with clips in the afternoon of the day before anthesis and pollination was done the next day between 0060 and 0900. 'WL 92' male parent was used for pollen provision to all other graft combinations and control; however, the pollen used to pollinate female flowers of tetraploid plants was from the respective diploid plants with similar name to the rootstocks, that is, Nun 9075/ST 101 was pollinated with pollen from Nun 9075/WL 92 plants. Two main shoots and only one fruit were allowed in every plant.

2.4. Plant measurements, harvesting and fruit analysis

Two months after transplanting, plant growth measurements were done on main stem length (cm) by using a measuring tape, diameter of the main stem (mm) was measured by using a digital vernier caliper (Mitutoyo CD-15D), and number of nodes were counted from the base to the tip of the main stem length.

Fruits were harvested having completely dried stipule and tendrils on the same node (Karaca et al., 2012). Harvesting was conducted from 27 June 2016 to 11 July 2016 in Adana and only on one day, 30 June 2016, in Antalya for 2016. In 2017 harvesting was done on 10 July 2017 and 12 July 2017 in Adana and 5 July 2017 in Antalya. During harvesting, all fruits were weighed using a weighing balance for total yield (kg/m^2) and from every replication 3 fruits were taken for fruit analysis in terms of mean fruit weight (g), fruit length (cm), fruit diameter (cm), seed yield (g/fruit), and weight of 1000 seeds (g).

2.5. Seed extraction and seed analysis

Fruits were shallow cut longitudinally to avoid damaging the seeds and the seeds were extracted by scooping the pulp with seeds by hand and put into 20-L containers covered well with a lid. Every replicate was put in a separate container and left in the greenhouse where the temperature was high (about 45–50 °C) for 4 days to ferment. After fermentation the seeds were stirred well using a long stick to separate them from the pulps and thoroughly washed with clean water. The well-washed seeds were put on very fine wire mesh and left on racks at 25 °C to dry. Some of the well-dried seeds from 3 fruits in every replication were counted and weighed to get the number of seeds per fruit, determination of weight of 1000 seeds, and embryo and seed coat ratio determination, while other seeds were stored for seed quality analysis. In the seed quality experiments, seeds were analyzed by germination and emergence tests, and all seeds before testing were sterilized with 3% sodium hypochloride for 10 min (Barbosa et al., 2016). All preparations for seed sterilization and sowing were carried out in a laminar flow hood to avoid any kind of contamination. In the seed germination test (between paper) four replications and 10 seeds of each replications were used. Seeds were placed between blot paper in petri dishes, slightly moistened, and stored in the incubator at 25 °C. Germinated seeds were counted daily and removed, and finally germination percentage and germination rate were calculated. For the seed emergence test, fine inert sand was collected from running water deposits, sterilized in an autoclave at 130 °C for 1 h, and then left to cool. For each graft combination and control seeds were sown in a plastic tray of 45 cm × 30 cm × 8.5 cm, with 4 replications having 10 seeds per replicate and left on the shelves at room temperature. Emerged seeds were counted by cutting the protruding plumule above the surface using a pair of scissors.

2.6. Statistical evaluation

The experiment was conducted as one factor (rootstock) randomized complete block design combined over years. The obtained data were analyzed using the statistical software JMP (v8.00, SAS Institute Inc., Cary, NC, USA). ANOVA was carried out to determine the effects of the rootstocks and years on examined parameters. A least significant difference test was performed to examine differences among the different groups. Comparisons that yielded *** = $P \leq 0.001$, ** = $P \leq 0.01$ and * = $P \leq 0.05$ were considered to be statistically significant. All percentages were transformed to arcsin values (Açıkgöz, 1990) for analysis of variance.

3. Results and discussion

3.1. Plant measurements

Data of main stem length (cm), main stem diameter (mm), and number of nodes are presented in Table 2. There was significant difference among graft combinations in main stem length (LSD = 36.26) in Antalya. The longest main stems were obtained from Nun 9075/ST 101 and Argentario/ST 101 graft combination (312.7 cm and 293.6 cm, respectively), which are in the same statistical group. The lowest value was obtained from the control (188.3 cm) but there was no significant difference among graft combinations in years and rootstock–year interaction on main stem in Antalya. In Adana, a significant difference was observed among graft combinations in main stem length for both years, rootstocks, and their interactions. The highest value was obtained in Argentario/ST 101 (341.3 cm) while controls resulted in a lower main stem length (233.1 cm) compared to other graft combination. However, the second year resulted in a higher value compared to the first year in Adana.

In Antalya, significant difference was obtained between years in main stem diameter with a higher value obtained in 2016 (11.1 mm) and a lower value was obtained in 2017 (8.8 mm). No significant difference was obtained among graft combinations. However, in Adana there was a significant difference among graft combinations and an interaction was found between rootstock and year, while year had no effect on main stem diameter. The highest main stem diameter value was obtained in Argentario/ST 101 while the lowest was in nongrafted controls. In both Antalya and

Table 2. Main stem length, main stem diameter, and number of nodes in Antalya and Adana in both years.

	Rootstock–scion combination	Main stem length (cm)		Mean of rootstock	Main stem diameter (mm)		Mean of rootstock	Number of nodes		Mean of rootstock
		2016	2017		2016	2017		2016	2017	
Antalya	Argentario/ST 101	324.4	262.7	293.6 A	11.2	9.3	10.2	40.7	28.6	34.7
	Nun 9075/ST 101	321.9	303.5	312.7 A	11.2	9.4	10.3	42.3	32.0	37.1
	PI 296341/ST 101	250.2	249.0	249.6 B	11.9	8.5	10.2	36.1	28.9	32.5
	Control	194.0	182.5	188.3 C	10.2	8.2	9.2	33.1	27.3	30.2
	Mean of year	272.6	249.5		11.1 A	8.8 B		38.1 A	29.2 B	
	LSD_{year} = N.S. LSD_{rstock}*** = 36.26 $LSD_{yearxrstock}$ = N.S.				LSD_{year}*** = 0.84 LSD_{rstock} = N.S. $LSD_{yearxrstock}$ = N.S.			LSD_{year}*** = 0.41 LSD_{rstock} = N.S. $LSD_{yearxrstock}$ = N.S.		
Adana	Argentario/ST 101	208.9 c	341.3 a	275.1 A	12.9 a	13.0 a	12.9 A	27.2	38.1	32.6
	Nun 9075/ST 101	219.9 c	267.8 b	243.8 B	11.3 bc	12.6 ab	11.9 B	26.9	31.6	29.3
	PI 296341/ST 101	154.4 d	288.4 b	221.4 C	10.5 cd	9.2 de	9.8 C	29.9	34.9	32.4
	Control	115.2 e	233.1 c	174.1 D	7.9 e	9.5 d	8.7 D	22.9	34.3	28.6
	Mean of year	174.6 B	282.6 A		10.7	11.1		26.7 B	34.8 A	
	LSD_{year}*** = 14.21 LSD_{rstock}*** = 20.1 $LSD_{yearxrstock}$*** = 28.4				LSD_{year} = N.S. LSD_{rstock}*** = 0.93 $LSD_{yearxrstock}$* = 1.31			LSD_{year}*** = 3.19 LSD_{rstock} = N.S. $LSD_{yearxrstock}$ = N.S.		

(1): Differences between the means are shown with different letters
(2): N.S.: Not significant, ***: $P \leq 0.001$; **: $P \leq 0.01$; *: $P \leq 0.05$

Adana no significant difference was obtained among graft combinations in number of nodes. The only significant difference was found between years with 2016 resulting in the highest value in number of nodes (38.1) in Antalya and 2017 (34.8) in Adana. The results indicated that plant growth traits are affected by grafting and Argentario and Nun 9075 commercial rootstocks performed better that PI 293341 and the control. The results of this study in terms of main stem diameter agree with the results reported by Edelstein et al. (2017), using interspecific *Cucurbita* hybrid rootstocks. In considering the length of the main stem, the results are higher than those reported by Alan et al. (2007), who used different commercial *Cucurbita* hybrid (TZ 148 and RS 841) and *L. siceraria* rootstocks, and Alan et al. (2017), who used *Lagenaria* and commercial ('Shintoza F90' and 'Obez') rootstocks.

3.2. Total yield and fruit measurements

Total yield, mean fruit weight, fruit length, and fruit diameter are presented in Table 3 and are seen to be significantly different between graft combinations in both locations and years. The interactions between year and rootstock for all the traits except for fruit diameter in Adana were also significant. Among graft combinations Argentario/ST 101 and Nun 9075/ST 101 had higher values than PI 296341/ST 101 and the control in terms of all examined parameters. The highest yields in Antalya were obtained from Nun 9075/ST 101 (1.98 kg/m^c) and Argentario/ST 101 (1.95 kg/m^2) in 2017 while the control plants had the lowest yields in both years (0.74 kg/m^2 and 0.64 kg/m^2, respectively). Similarly, in Adana, Argentario and Nun 9075 rootstocks resulted in higher yields compared to PI 296341 and the ungrafted control. Yield was higher in 2017 than in 2016 in both locations.

Rootstock and year interaction had significant effect on fruit weight in Antalya. The graft combinations of Nun 9075/ST 101 and Argentario/ST 101 resulted in higher fruit weights (4942 g and 4689 g) while the nongrafted control plants produced the lowest fruit weight (2951 g). In Adana, Argentario/ST 101 (3725 g) and Nun 9075/ST 101 (3648 g) produced higher yield than PI 296341/ST 101 (2104 g) and the control (1082 g). Mean fruit weight was significantly higher in 2017 than in 2016 in Antalya.

Fruit length and diameter were significantly affected by rootstock in Antalya and Adana. Nun 9075/ST 101 and Argentario ST/101 combinations had longer fruits (23.1 cm and 21.8 cm) than PI 296341/ST 101 (20.1 cm) and the control (17.3 cm) in Antalya. Similarly, Argentario ST/101 (19.9 cm) and Nun 9075/ST 101 (19.2 cm) had the highest values in Adana while the lowest value was obtained from the control as 12.6 cm. The year effect found to be significant only in Adana and 2017 resulted in higher (17.9 cm) values than 2016 (15.6 cm), while year and rootstock interactions were significant in both years and locations. Considering fruit diameter Nun 9075/ST 101 had the widest fruits (22.3 cm) than other graft combinations and control fruits had the lowest value (15.9 cm) in Antalya. Among the graft combinations Argentario ST/101 (19.9 cm) and Nun-9075/ST 101 (19.9 cm) performed better than PI 296341/ST 101 (16.1 cm) and the control (13.1 cm) in Adana in terms of fruit diameter. Year factor was found to be significant only in Adana, with a higher value in 2017. Grafted plants resulted in higher values in all parameters compared to nongrafted plants (control); these results are in line with previous studies (Nelson, 2007; Fredes et al., 2016; Alan et al., 2017). The robust *Cucurbita* and *Lagenaria* rootstocks produce high watermelon yield and are highly compatible with watermelon (Davis et al., 2008b). As Savvas et al. (2011) explained, the increased yield largely resulted from the increased number of fruits. Colla et al. (2006) reported the increase in yield as a result of grafting was expressed by the increased fruit mass. Furthermore, the effect of rootstocks on yield of watermelon might be more positive than agronomic factors, when considering all other factors constant.

3.3. Seed yield

There was a significant difference between graft combinations in seed yield (g/fruit), number of seed per fruit, and weight of 1000 seeds in both locations (Table 4). The highest seed yields were obtained in Argentario/ST 101 (5.6 g/fruit) and Nun 9075/ST 101 (5.5 g/fruit), while the lowest was in the nongrafted control (2.0 g/fruit) plants in Antalya. In Adana, only ST 101 grafted onto Nun 9075 produced significantly higher seed yield (2.9 g/fruit) compared with the other rootstocks and control. Year effect was found to be significant only in Adana and was higher in 2016 than in 2017. The greatest number of seeds per fruit was obtained from Nun 9075/ST 101 (111.3, 71.2) and from Argentario/ST 101 (111.1, 53.1) in Antalya and Adana, respectively.

Analysis of variance showed that weight of 1000 seeds was significantly different between graft combinations in both locations. The heaviest seeds were obtained from Argentario/ST 101 (50.4 g), Nun 9075/ST 101 (49.5 g), and PI 296341/ST 101 (49.5 g), while the control had the lightest seeds (43.5 g) in Antalya. In Adana Argentario/ST 101 (541.8 g) was followed by Nun 9075/ST 101 (39.5 g), PI 296341/ST 101 (7.5 g), and the control (35.3 g). Year effect was found to be significant only in Adana and was higher in 2016 than in 2017. According to the analysis of variance there were no year–rootstock interactions in any of the examined seed parameters.

Our results indicated that grafting and type of rootstock improved seed yield, seed number per fruit, and seed weight. Nun 9075/ST 101 and Argentario/ST 101 graft combinations produced higher seed number and seed weight. Our findings are in agreement with Nerson (2005),

Table 3. Total yield, mean fruit weight, length, and diameter in Antalya and Adana in both years.

	Rootstock–scion combination	Total yield (kg/m^2)		Mean of rootstock	Mean fruit weight (g)		Mean of rootstock	Fruit length (cm)		Mean of rootstock	Fruit diameter (cm)		Mean of rootstock
		2016	2017		2016	2017		2016	2017		2016	2017	
Antalya	Argentario/ST 101	1.02 cd	1.95 a	1.49 AB	4038 cd	5341 ab	4689 A	21.9 b	21.8 b	21.8 A	20.8 b	21.3 b	21.0 B
	Nun 9075/ST 101	1.22 bc	1.98 a	1.61 A	4467 c	5416 a	4942 A	24.9 a	21.3 b	23.1 A	23.2 a	21.4 b	22.3 A
	PI 296341/ST 101	1.16 bc	1.49 b	1.33 B	3571 de	4520 bc	4046 B	20.2 bc	19.9 bc	20.1 B	18.6 c	20.6 b	19.6 C
	Control	0.74 de	0.64 e	0.69 C	3160 e	2741 e	2951 C	16.0 d	18.5	17.3 C	14.9 d	17.0 c	15.9 D
	Mean of year	1.04 B	1.52 A		3809 B	4505 A		20.7	20.4		19.3	20.1	
	LSD_{year}*** = 0.18 LSD_{rstock}*** = 0.25 $LSD_{yearxrstock}$** = 0.36				LSD_{year}** = 430 LSD_{rstock}*** = 608 $LSD_{yearxrstock}$* = 860			LSD_{year} = N.S. LSD_{rstock}*** = 1.51 $LSD_{yearxrstock}$** = 2.14			LSD_{year} = N.S. LSD_{rstock}*** = 1.11 $LSD_{yearxrstock}$** = 1.57		
Adana	Argentario/ST 101	1.09 cd	1.81 a	1.45 A	3388 ab	4063 a	3725 A	17.3 c	22.4 a	19.9 A	18.7	21.1	19.9 A
	Nun 9075/ST 101	1.38 bc	1.46 ab	1.42 A	4008 a	3288 b	36.48 A	19.2 b	19.2 b	19.2 A	19.9	20.1	19.9 A
	PI 296341/ST 101	0.85 de	0.88 de	0.87 B	1698 d	2511 c	2104 B	14.2 d	16.5 c	15.4 B	15.2	16.9	16.1 B
	Control	0.38 f	0.58 ef	0.48 C	866 e	1298 de	1082 C	11.7 e	13.5 d	12.6 C	11.9	14.1	13.1 C
	Mean of year	0.93 B	1.18 A		2490	2790		15.6 B	17.9 A		16.5 B	18.1 A	
	LSD_{year}*** = 0.18 LSD_{rstock}*** = 0.25 $LSD_{yearxrstock}$* = 0.36				LSD_{year} = N.S. LSD_{rstock}*** = 478.3 $LSD_{yearxrstock}$* = 676.4			LSD_{year}*** = 0.85 LSD_{rstock}*** = 1.21 $LSD_{yearxrstock}$** = 1.71			LSDyear*** = 0.81 $LSD_{rstock***=}$ 1.14 $LSD_{yearxrstock}$ = N.S.		

(1): Differences between the means are shown with different letters
(2): N.S.: Not significant, ***: P ≤ 0.001; **: P ≤ 0.01; *: P ≤ 0.05

Table 4. Seed yield, number of seeds per fruit, and weight of 1000 seeds in Antalya and Adana in both years.

	Rootstock–scion combination	Seed yield (g/fruit)		Mean of rootstock	Number of seeds per fruit		Mean of rootstock	Weight of 1000 seeds (g)		Mean of rootstock
		2016	2017		2016	2017		2016	2017	
Antalya	Argentario/ST 101	5.4	5.9	5.6 A	106.5	115.7	111.1 A	50.4	50.4	50.4 A
	Nun 9075/ST 101	5.2	5.9	5.5 A	107.5	115.1	111.3 A	48.4	50.6	49.5 A
	PI 296341/ST 101	3.4	5.2	3.4 B	68.5	70.2	69.3 B	48.7	50.4	49.5 A
	Control	2.4	1.6	2.0 C	61.7	34.8	48.3 C	41.4	45.7	43.5 B
	Mean of year	4.1	4.2		86.0	83.9		47.2	49.3	
	LSD$_{year}$ = N.S. LSD$_{rstook}$*** = 0.94 LSD$_{yearxrstock}$= N. S.				LSD$_{year}$ = N.S. LSD$_{rstook}$ = 20.1 LSD$_{yearxrstock}$= N. S.			LSD$_{year}$ = N.S. LSD$_{rstook}$ = 3.85 LSD$_{yearxrstock}$ = N.S.		
Adana	Argentario/ST 101	3.0	1.5	2.2 B	52.9	53.2	53.1 A	49.6	34.0	41.8 A
	Nun 9075/ST 101	3.3	2.7	2.9 A	68.3	74.1	71.2 A	45.9	33.2	39.5 AB
	PI 296341/ST 101	1.4	0.9	1.2 C	27.8	28.1	27.9 B	42.8	32.2	37.5 BC
	Control	0.5	0.9	0.7 C	12.1	17.7	14.9 B	38.0	32.5	35.3 C
	Mean of year	2.0 A	1.5 B		40.3	43.3		44.1 A	32.9 B	
	LSD$_{year}$* = 0.50 LSD$_{rstock}$*** = 0.71 LSD$_{yearxrstock}$ = N.S.				LSD$_{year}$= N. S. LSD$_{rstock}$***= 23.0 LSD$_{yearxrstock}$= N.S.			LSD$_{year}$*** = 2.67 LSD$_{rstock}$*** = 3.78 LSD$_{yearxrstock}$ = N.S.		

(1): Differences between the means are shown with different letters
(2): N.S.: Not significant, ***: P ≤ 0.001; **: P ≤ 0.01; *: P ≤ 0.05

who explained that the increased seed yield per fruit was increased with the fruit weight and that was caused by the increase in both seed number and seed weight.

Analysis of variance indicated that grafting did not affect the percentage of seed germination in both years in Antalya and Adana (Table 5). According to Phat et al. (2015), a poor germination rate due to weak embryos, thick seed coats, and larger air spaces is a serious challenge, restricting production of triploid seedless watermelon. Here, the rootstocks had no effect on germination rate, which was 67.5%–80% for all seed lots. Our results are in agreement with Liu et al. (2010), who reported the germination rate of triploid watermelon is generally low, at a rate of 60%–80% compared to a germination rate of 95% in diploid plants. Days to germination was found to be nonsignificant between rootstocks and years in Antalya. Argentario/ST 101, Nun 9075/ST 101, and the control were in the same statistical group while PI 296341/ST 101 resulted in the lowest value with an average of 5.3 days in Adana.

Seed emergence percentage was higher in 2016 (8%) than in 2017 (70%) in Antalya (Table 5). There was no significant difference between rootstocks in terms of seed emergence percentage in Antalya; nevertheless Nun 9075/ST 101 performed as the best combination with 74.2% in Adana. The relatively low seed emergence that we obtained can be due to the weak embryo and the lack of energy required to overcome the resistance of a thick embryo coat as reported by Path et al. (2015). Days to emergence was affected significantly by rootstock, year, and rootstock–year interactions for both locations. The lowest value (5.5 days) resulted in PI 296341/ST 101 combination in 2016, while Nun 9075/ST 101 combination had the highest value (8.8 days) in 2017 in Antalya. Similarly the lowest value (4.5 days) was obtained from PI 296341/ST 101 in 2017, while the highest value (7.2 days) was found in Argentario/ST 101 in 2017 in Adana. Ratios of seed coat weight/total seed weight and embryo weight/total seed weight are presented in Table 6.

In the ratio of seed coat weight/total seed weight significant differences were found between graft combinations in both years in Antalya (Table 6). All rootstocks except Nun 9075 were in the same statistical group with the control. The control (66.1%), PI 296341/ST 101 (66.1%), and Argentario/ST 101 (64.9%) had higher values than Nun 9075/ST 101 (60.7%). Only year factor resulted in significant differences in Adana. Embryo weight ratio was 27.3% in 2016 and 36.2% in 2017.

Even though grafting and rootstock effects on watermelon yield, plant vigor, fruit quality, fruit shelf

Table 5. Seed germination and emergence percentages and days to germination and emergence in Antalya and Adana in both years.

	Rootstock–scion combination	Seed germination percentage (%)		Mean of rootstock	Days to germination (day)		Mean of rootstock	Seed emergence percentage (%)		Mean of rootstock	Days to emergence		Mean of rootstock
		2016	2017		2016	2017		2016	2017		2016	2017	
Antalya	Argentario/ST 101	73.3 (58.9)	67.5 (55.4)	70.4 (57.2)	4.4	4.2	4.3	86.7 (68.8)	70.0 (56.8)	78.3 (62.8)	6.1 ef	7.4 cd	6.74 C
	Nun 9075/ST 101	70.0 (56.9)	72.5 (58.6)	71.2 (57.8)	4.3	4.3	43	83.3 (69.0)	75.0 (60.1)	79.2 (64.6)	6.7 de	8.8 a	7.75 A
	PI 296341/ST 101	70.0 (56.9)	70.0 (56.9)	70.0 (56.9)	4.0	4.0	4.0	85.0 (70.3)	70.0 (56.9)	77.5 (63.6)	5.5 f	8.5 ab	6.99 BC
	Control	70.0 (56.9)	70.0 (56.9)	70.0 (56.9)	4.3	4.3	4.3	65.0 (53.8)	65.0 (53.8)	65.0 (53.7)	7.4 cd	7.7 bc	7.51 AB
	Mean of year	70.8 (57.4)	70.0 (56.9)		4.3	4.2		80.0 (65.4)A	70.0 (56.9) B		6.4 B	8.1 A	
	LSD_{year} = N.S. LSD_{rstock} = N.S. $LSD_{yearxrstock}$ = N.S.				LSD_{year} = N.S. LSD_{rstock} = N.S. $LSD_{yearxrstock}$ = N.S.			$LSD_{year}{}^{*}$ = 6.4 LSD_{rstock} = N.S. $LSD_{yearxrstock}$ = N.S.			$LSD_{year}{}^{***}$ = 0.46 $LSD_{rstock}{}^{*}$ = 0.65 $LSD_{yearxrstock}{}^{**}$ = 0.91		
Adana	Argentario/ST 101	76.7 (61.2)	72.5 (58.5)	74.6 (59.8)	4.3	4.3	4.3 B	66.7 (54.9)	65.0 (53.8)	65.8 (54.4) B	7.18 a	5.00 cd	6.09 B
	Nun 9075/ST 101	80.0 (63.4)	75.0 (60.1)	77.5 (61.8)	3.9	4.0	3.9 B	73.3 (59.5)	75.0 (60.1)	74.2 (59.8) A	6.19 b	5.38 c	5.79 BC
	PI 296341/ST 101	70.0 (56.8)	72.5 (58.5)	71.3 (57.6)	5.6	5.1	5.3 A	66.7 (54.8)	65.0 (53.8)	65.8 (54.3) B	6.41 b	4.50 d	5.46 C
	Control	76.7 (61.2)	75.0 (60.1)	75.8 (60.7)	4.3	4.2	4.2 B	65.0 (53.8)	65.0 (53.8)	65.0 (53.8) B	6.79 ab	6.40 b	6.59 A
	Mean of year	75.8 (60.7)	73.8 (59.3)		4.5	4.4		67.9 (55.7)	67.5 (55.4)		6.64 A	5.32 B	
	LSD_{year} = N.S. LSD_{rstock} = N.S. $LSD_{yearxrstock}$ = N.S.				LSD_{year} = N.S. $LSD_{rstock}{}^{***}$ = 0.35 $LSD_{yearxrstock}$ = N.S.			LSD_{year} = N.S. $LSD_{rstock}{}^{*}$ = 4.58 $LSD_{yearxrstock}$ = N.S.			$LSD_{year}{}^{***}$ = 0.33 $LSD_{rstock}{}^{***}$ = 0.47 $LSD_{yearxrstock}{}^{**}$ = 0.67		

(1): Differences between the means are shown with different letters
(2): N.S.: Not significant, ***: $P \leq 0.001$; **: $P \leq 0.01$; *: $P \leq 0.05$
(3): Angle transformed data were bracketed

Table 6. Ratio of seed coat weight/total seed weight and ratio of embryo weight/total seed weight in Antalya and Adana in both years.

	Rootstock–scion combination	Seed coat (%)		Mean of rootstock	Embryo (%)		Mean of rootstock
		2016	2017		2016	2017	
Antalya	Argentario/ST 101	73.9 (59.3)	55.9 (48.4)	64.9 (53.9) A	26.0 (30.7)	31.6 (34.2)	33.9 (32.4) B
	Nun 9075/ST 101	68.1 (55.6)	53.3 (46.9)	60.7 (51.3) B	31.9 (34.4)	35.9 (36.7)	33.9 (35.5) A
	PI 296341/ST 101	72.2 (58.2)	57.2 (49.1)	64.7 (53.7) A	27.8 (31.8)	29.5 (32.9)	28.6 (32.3) B
	Control	74.5 (59.7)	57.6 (49.4)	66.1 (54.7)A	25.5 (30.3)	28.7 (32.4)	27.1 (31.3) B
	Mean of year	72.2 (58.2) A	56.0 (48.5)B		27.8 (31.8) B	31.4 (34.0) A	
		LSD_{year}*** = 1.57 LSD_{rstock}* = 2.22 $LSD_{yearxrstock}$ = N.S.			LSD_{year}* = 2.15 LSD_{rstock}* = 3.04 $LSD_{yearxrstock}$ = N.S.		
Adana	Argentario/ST 101	71.7 (57.9)	51.8 (46.0)	61.7 (51.9)	28.3 (32.1)	38.3 (38.2)	33.3 (35.2)
	Nun 9075/ST 101	73.9 (59.4)	55.3 (48.1)	64.6 (53.7)	26.1 (30.6)	34.7 (36.1)	30.4 (33.3)
	PI 296341/ST 101	73.3 (58.9)	54.4 (47.5)	63.8 (53.2)	26.7 (31.1)	35.7 (36.6)	31.2 (33.9)
	Control	72.1 (58.2)	53.7 (47.2)	62.9 (52.7)	27.9 (31.8)	36.3 (37.0)	32.1 (34.4)
	Mean of year	72.7 (58.6) A	53.8 (47.2) B		27.3 (31.4) B	36.2 (36.9) A	
		LSD_{year}*** = 1.75 LSD_{rstock}= N.S. $LSD_{yearxrstock}$ = N.S.			LSD_{year}***= 1.78 LSD_{rstock} = N.S. $LSD_{yearxrstock}$ = N.S.		

(1): Differences between the means are shown with different letters
(2): N. S.: Not significant, ***: $P \leq 0.001$; **: $P \leq 0.01$; *: $P \leq 0.05$
(3): Angle transformed data were bracketed

life, and storage quality were widely examined in several studies (Yetişir and Sari, 2003; Alan et al., 2007; Davis et al., 2008a; Turhan et al., 2012; Karaca et al., 2012; Çandır et al., 2013, Kyriacou and Soteriou, 2015; Fredes et al., 2016; Özdemir et al., 2016), effects of grafting and rootstocks on triploid watermelon seed production as yield and seed attributes as number, weight, germination, and emergence percentages have not been determined to date.

The present study indicates that grafting onto *Cucurbita* interspecific hybrid and *Lagenaria* rootstocks improves triploid seed yield, number of seeds per fruit, and seed weight and might be considered as a practice to obtain higher yield and quality of triploid seeds used for production of seedless watermelon.

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