

Article

Watermelon Rootstock/Scion Relationships and the Effects of Fruit-Thinning and Stem-Pruning on Yield and Postharvest Fruit Quality

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Abstract: This study examined the effects of stem-pruning and fruit-thinning on the yield of marketable watermelon fruit (>5 kg) and watermelon quality after four days of postharvest storage at 22 °C (marketing simulation). We examined the fruits from non-grafted and grafted plants (TZ and Nurit rootstocks) for two consecutive years. Grafting increased the number of marketable fruit per m². The weight of the average marketable fruit was increased by pruning, but was not affected by thinning or by the choice of rootstock. The level of total soluble solids was higher among fruits from Nurit rootstock. Flesh texture was improved by grafting, but was not affected by thinning or pruning. Thinning improved the taste of the fruit significantly better than stem-pruning did. Grafting (both rootstocks) was associated with crispier fruits. The fruits from Nurit-grafted plants tasted best. The combination of grafting + fruit-thinning increased the fruit lycopene content. The highest levels of vitamin C were found among the fruit from Nurit-grafted plants and the pruned + Nurit-grafted plants, in particular. Overall, fruit quality was affected mainly by grafting onto Nurit rootstock in combination with fruit-thinning and less by stem-pruning. However, not all internal and nutritional quality parameters were significantly affected by the grafting + fruit-thinning treatment.

Keywords: *Citrullus lanatus*; *Cucurbita maxima* × *Cucurbita moschata*; fruit quality; postharvest

1. Introduction

About 95% of the watermelon plants in Israel are grafted onto pumpkin rootstock due to the high levels of soil-borne pathogens in most local soils. Grafting is a common technique in many parts of the world, used not only to manage soil-borne diseases, but also to improve crop response to a variety of abiotic stresses and improve fruit quality [1]. However, one issue that continually arises in this context is the loss of fruit quality that is often reported when watermelon is grafted onto *Cucurbita* spp. [2,3]. Davis et al. [4] reported that sugars accumulate in the fruit toward the end of fruit development and ripening, depending upon the rootstock–scion combination, while the fruits of grafted and non-grafted plants acquire their rind color at about the same time. This result in growers harvesting too early and those early-harvested fruits tend to be less sweet and have a squash-like flavor. Grafting can also

increase the firmness of watermelon flesh, which can be an advantage or a disadvantage depending on the scion cultivar [4].

In plants, the developing fruits are the major sink, and crop productivity and quality depend on an appropriate source–sink relationship. The limitation of vegetative (leaf and stem) growth increases the amounts of photoassimilates transferred to fruits [5]. In addition, limiting the number of fruits per plant often improves fruit size and quality by enhancing the partitioning of assimilates to the remaining fruit [6]. Therefore, stem pruning and fruit thinning offer the opportunity to adjust the fruit load of each individual plant according to its vegetative vigor [7].

Crop load and vigorous growth affect yield and fruit quality [8]. Studies have shown that grafting improves the growth vigor and fruiting characteristics of cucurbitaceous vegetable plants under normal, as well as stress conditions [9]. Grafted watermelon plants produce more lateral vines than non-grafted plants, as well as more leaves, which might affect fruit quality [10,11]. To the best of our knowledge, there have been no previous studies of the effects of pruning and fruit-thinning on watermelon quality after harvest. Therefore, the objective of the present study was to examine the effects of stem-pruning and fruit-thinning on the quality of watermelon (*Citrullus lanatus*) fruit harvested from grafted and non-grafted plants over two consecutive years.

2. Materials and Methods

2.1. Plant Materials and Growing Conditions

Seedless watermelon (*Citrullus lanatus* (Thunb.) Matsum. and Nakai) cv. 1262 (oval shape, green skin with dark green stripes and red flesh; Gadot Agro, Kidron, Israel) was used in this study. The experiment was conducted for two consecutive years, in 2017 and 2018, in an open field in loessial (sierozem) soil at the Eden Experimental Station, which is located in the Syrian–African rift, in the southern part of the Bet-She’an Valley (32°28.162 N, 35°29.425 E; Alt.: –130 m). This cultivar is grown in this area for the local market during the early spring to early summer.

The field had a history of cucurbit production and infestation with *Macrophomina phaseolina*, the causal agent of charcoal rot and vine decline in several cucurbits and other vegetable and field crops. The experiment was set in 15 beds (1.93 m wide × 180 long). Every three beds served as a block, with an empty bed to separate between the blocks. Each treatment was set in all three beds for 15 m long, and were used for data collection. The treatments (main plots) were arranged randomly in complete block design with five replications per treatment (each replicate in area of 3 beds × 30 m long). The treatments that included the grafted and non-grafted transplants (sub plot) were arranged next to each other in each fumigation plot to establish a split-plot design. Fumigation treatments were conducted at the end of August each year. A wide, impermeable Ozgard plastic sheet (transparent film 0.04 mm thick, Ginegar, Kibbutz Ginegar, Israel) was manually laid over each three beds. Metam sodium (MS; Adama-Agan Ltd., Ashdod, Israel) was injected at a rate of 60 mL m² through polyethylene irrigation drip lines placed under the plastic prior to mulching, two weeks after the plastic mulch had been laid. The plastic film was kept on the mulched plot for an additional three weeks and then manually removed.

The seedlings of watermelon were grafted using the “hole-insertion” method [1] onto rootstocks of one of the two commercial *Cucurbita* spp. hybrids: ‘TZ-148’ (*Cucurbita maxima* Duchesne × *Cucurbita moschata* Duchesne, Tezier, France) and ‘Nurit’, which is a local nursery-selected rootstock (Hishtil Ltd., Nehalim, Israel). Non-grafted (NG) 1262 plants were used as a control.

Grafted and non-grafted transplants were prepared during the month of November and planted in an r regular plant stand for a grafted plant (2500 plants h⁻¹, 1 m space between seedlings that were planted at the end of January). Each subplot consisted of 30 plants. The experiment was set up in a factorial split-plot design with five replicates for each treatment. The plants were grown under low plastic tents, which were removed two months after planting. Beehives were introduced to the field during the fruit setting months, to ensure adequate pollination and fruiting. The entire field

was irrigated using drip irrigation and farms as per recommendation for commercial watermelon production in the region.

2.2. Pruning and Thinning

Pruning and thinning were carried out one month after anthesis, when fruits were approximately 3 cm in diameter. Pruned branches were cut so that only three fruits closest to the main part of the plant remained. The thinning treatment involved removing all fruits, except for the three closest to the main part of the plant, without cutting the branch itself.

2.3. Vine Decline, Fruit Yield and Fruit Quality after Storage

In the middle of May, the level of vine decline was determined by counting the number of collapsing vines. The watermelon fruits were manually harvested, counted and weighed. Each year, 12 market-quality fruits were pooled from all 4 repetitions (over 5 kg) and were transferred to the Department of Postharvest Science in Bet Dagan, Israel, within 8 h of harvest, for postharvest quality assessments. After 4 days of storage at 22 °C (simulation of local marketing conditions), we analyzed the quality parameters of eight fruits (our of 12 fruits) of uniform size, shape and rind color, from each treatment (i.e., each rootstock × tissue-removal treatment combination).

The aspects of sensory fruit quality were evaluated after four days of storage at 22 °C and 65–70% RH (simulation of local marketing conditions). Each treatment included eight fruits that were selected for harvest based on the dryness of the tendril adjacent to the fruit stem and stem dryness, fruit rind color and ground spot color. Total soluble solid (TSS) content was measured with an Atago (Tokyo, Japan) digital refractometer by squeezing about 2 × 2 × 2 cm of flesh tissue that was taken from the heart of the fruit (inner flesh). Results were obtained as Brix values. Each year, 8 fruit texture and overall taste were evaluated by seven trained tasters, who examined two 3 × 3 × 3 cm sections cut from the heart of the fruit, as follows. The texture was scored on a scale of 1–3, with 1 = very soft and mealy; 2 = a bit crispy; and 3 = very crispy and a bit dry and gummy. Overall taste was scored on a scale of 1–3: 1 = very bad flavor with severe bitterness or off-flavor; 2 = reasonable flavor and a bit crispy and 3 = excellent flavor (sweet, crispy and juicy, no off-flavor or bitterness, no gumminess).

The lycopene content and vitamin C content of those same eight fruits were analyzed as follows. Lycopene was extracted and quantified by taking 50 g tissue/sample (fruit) from the heart of fruit, slicing the tissue and storing it at −80 °C until use. The frozen watermelon tissue was ground with a mortar and pestle. A 5 g duplicated sample was put into two glass test tubes that (for each tube) contained a mixture of 4 mL hexane, 2 mL ethanol and 2 mL acetone. Following 15 min of orbital shaking at 180 rpm in the dark, 3 mL of deionized water were added to each vial, followed by an additional 5 min of shaking. Vials were then held for 5 min at room temperature for phase separation. Lycopene concentration in the upper hexane layer was quantified against pure hexane using a Jasco V-550 UV–VIS spectrophotometer at 503 nm using the extinction coefficient of $17.2 \times 10^4 \text{ M}^{-1} \text{ cm}^{-1}$. The results were obtained as $\mu\text{g g}^{-1}$ fresh weight (FW). Vitamin C (ascorbic acid (AA)) was measured with the HI 3850 Ascorbic Acid Test Kit (Hanna Instrument, Bucharest, Romania) using 5 g duplicated fresh samples taken from the heart of the fruit flesh and the results were expressed as mg vitamin C per 100 g fruit FW.

2.4. Statistical Analysis

Data on the yield of marketable fruit were collected and pooled from all four blocks for the two years. Fruit quality parameters were evaluated from 16 fruits by collecting and pooling the data from the two-year research (eight fruit per year) (uniform in size, weight and shape) per treatment from all four blocks. A 2-way factorial design by Tukey–Kramer tests (among rootstocks, and for pruning and thinning) were used to apply an analysis of variance (ANOVA) from 0.05 to 0.0001 using the JMP11 Statistical Analysis Software Program (SAS Institute Inc., Cary, NC, USA).

3. Results

Grafting significantly increased the number of marketable fruit compared with the non-grafted treatment (Table 1). The different rootstocks did not affect the number of marketable fruits in any of the treatments. There were fewer marketable fruits from the thinned and pruned plants, as compared with the control plants (neither pruned nor thinned). Significant interactions were observed between the grafting and the three tissue-removal treatments (i.e., no-removal control, fruit-thinning and stem-pruning). Among the Nurit-grafted plants, pruning significantly reduced the number of marketable fruit, as compared with the no-removal control. However, in the two other treatments, with the non-grafted and TZ-148 grafted plant, no significant differences were observed in the number of marketable fruits (Table 1).

Table 1. Effects of rootstock, pruning and fruit-thinning on the number of marketable fruits/m² (>5 kg) at harvest (means of two-year data).

Treatment/Rootstock	Control	Thinning	Pruning
Non-grafted	0.2 Ba ^z	0.3 Ba	0.3 Ba
Nurit	1.2 Aa	0.8 Aab	0.7 Ab
TZ-148	1.0 Aa	0.8 Aa	0.6 Aa
Analysis of variance (<i>p</i> -value)			
Grafting × control	*** (0.0024)		
Grafting × thinning	*** (0.0015)		
Grafting × pruning	*** (0.0045)		
Fruit removal × Non-grafted	NS		
Fruit removal × Nurit	** (0.049)		
Fruit removal × TZ-148	NS		

^z Values followed by the different uppercase letters are significantly different among the different rootstocks and the values followed by different lowercase letters are significantly different among the different tissue-removal treatments (pruning, fruit-thinning or non-removal control) at $\alpha = 0.05$. *, **, ***, and **** = significant at the 0.05, 0.01, 0.001 and 0.0001 levels, respectively. NS—not significant.

Pruning of the Nurit and TZ-grafted plants significantly increased the weights of marketable fruits, as compared to the harvest from the pruned, non-grafted plants (7.0, 6.9 and 5.1 kg, respectively; Table 2). The weight of marketable fruits was significantly increased by the interaction between grafting and pruning (Table 2). No significant differences were observed between the rootstocks in any of the three tissue-removal treatments. No interaction was found between any of the other treatments, although grafting increased the average marketable fruit weight (Table 2).

The parameters that reflect fruit sensory quality are shown in Table 3. Significant differences were found in the TSS contents of the fruits harvested from Nurit and TZ-grafted plants. The lowest TSS content was measured in TZ-grafted fruit, while the Nurit-grafted fruit had the highest TSS content. Thinning increased TSS content, but not significantly. Thinning and pruning increased the TSS content of fruits grown on non-grafted plants, but not significantly (Table 3).

Grafting significantly improved fruit texture, especially when it involved a TZ-148 rootstock, across the control, fruit-thinned and pruned plants (Table 3). However, the choice of Nurit or TZ-148 as rootstock did not significantly affect fruit texture. Grafting with Nurit and TZ-148 rootstocks significantly improved the overall taste among the fruits from the fruit-thinned plants, but not among the fruits from the plants that were pruned or the control (neither fruit-thinned nor pruned) plants. Pruning did not influence the taste of the fruits (Table 3).

Table 2. Effects of rootstock, pruning and fruit-thinning on average marketable fruit weight (>5 kg) at harvest (means of two year data).

Treatment/Rootstock	Control	Thinning	Pruning
Non-grafted	5.6 Aa ^z	5.3 Aa	5.1 Ba
Nurit	6.5 Aa	6.7 Aa	7.0 Aa
TZ-148	6.7 Aa	6.8 Aa	6.9 Aa
Analysis of variance (<i>p</i> -value)			
Grafting × control	NS		
Grafting × thinning	NS		
Grafting × pruning	**** (0.0001)		
Fruit removal × Non-grafted	NS		
Fruit removal × Nurit	NS		
Fruit removal × TZ	NS		

^z Values followed by the different uppercase letters are significantly different among rootstocks and the values followed by different lowercase letters are significantly different among the tissue-removal treatments (i.e., thinning, pruning or non-removal control) at $\alpha = 0.05$. *, **, ***, and **** = significant at the 0.05, 0.01, 0.001 and 0.0001 levels, respectively. NS—not significant.

Table 3. Effects of rootstock, pruning and fruit-thinning on the TSS, texture and taste of watermelon fruits after 4 days of storage at 22 °C ($n = 16$ fruits in two years).

Treatment/Rootstock	TSS—Heart (%)			Texture (1–3)			Taste (1–3)		
	Control	Thinning	Pruning	Control	Thinning	Pruning	Control	Thinning	Pruning
Non-grafted	9.5 Aab ^z	10.0 ABa	10.5 Aa	1.8 Ba	1.7 Ba	1.6 Ba	1.8 Ba	1.6 Ba	1.6 Aa
Nurit	11.5 Aa	11.5 Aa	10.8 Aa	2.0 ABa	2.0 Aa	1.9 ABa	2.1 Aa	2.2 Aa	1.8 Ab
TZ-148	7.0 Ba	7.8 Ba	7.4 Ba	2.2 Aa	2.1 Aa	2.2 Aa	1.8 Ba	2.0 Aa	1.7 Aa
Analysis of variance (<i>p</i> -value)									
Grafting × control	*** (0.0012)			* (0.05)			* (0.05)		
Grafting × thinning	** (0.017)			** (0.035)			**** (0.0001)		
Grafting × pruning	** (0.034)			*** (0.0027)			NS		
Fruit removal × Non-grafted	NS			NS			NS		
Fruit removal × Nurit	NS			NS			** (0.027)		
Fruit removal × TZ	NS			NS			NS		

^z Values followed by the different uppercase letters are significantly different among rootstocks and the values followed by different lowercase letters are significantly different among the different tissue-removal treatments (i.e., thinning, pruning and control) at $\alpha = 0.05$. *, **, ***, and **** = significant at the 0.05, 0.01, 0.001 and 0.0001 levels, respectively. NS—not significant.

The combination of grafting with thinning or pruning increased lycopene content, especially among the fruits grown on plants with the Nurit rootstock (68 $\mu\text{g/g}$ FW) as compared with the control plants (54 $\mu\text{g/g}$ FW). However, no significant differences in the lycopene content were observed between the two grafted rootstocks (Table 4). Vitamin C content was influenced by grafting and fruit-thinning (Table 4). The use of the Nurit rootstock significantly increased the vitamin C content of the harvested fruit, as compared with the non-grafted and TZ-grafted plants (14.8, 10.5 and 12.5 mg/100 g FW, respectively). A non-significant increase in vitamin C content was associated with pruning and Nurit and TZ rootstocks (Table 4).

Table 4. Effects of rootstock, pruning and thinning on the lycopene and vitamin C content of fruits after 4 days of storage at 22 °C ($n = 16$ fruits in two years).

Treatment/Rootstock	Lycopene ($\mu\text{g/g}$ FW)			Vitamin C ($\text{mg}/100$ g FW)		
	Control	Thinning	Pruning	Control	Thinning	Pruning
Non-grafted	52 Aab ^z	54 Ba	47 Bb	10.5 Bb	12.2 ABa	12.7 Aa
Nurit	50 Ab	68 Aa	53 Ab	14.8 Aa	14.5 Aa	15.0 Aa
TZ-148	50 Ab	62 ABa	52 Ab	12.5 ABab	11.0 Bb	13.5 Aa
Analysis of variance (p -value)						
Grafting \times control	NS			*** (0.008)		
Grafting \times thinning	** (0.03)			*** (0.0055)		
Grafting \times pruning	*** (0.0022)			NS		
Fruit removal \times Non-grafted	*** (0.0031)			*** (0.0042)		
Fruit removal \times Nurit	**** (<0.0001)			NS		
Fruit removal \times TZ	**** (<0.0001)			*** (0.0031)		

^z Values followed by the different uppercase letters are significantly different among rootstocks and the values followed by different lowercase letters are significantly different among the tissue-removal treatments (i.e., thinning, pruning and control) at $\alpha = 0.05$. *, **, ***, and **** = significant at the 0.05, 0.01, 0.001 and 0.0001 levels, respectively. NS—not significant.

4. Discussion

Fruits are the strongest sinks for photoassimilates in plants. To maximize the production of large and high-quality fruits, pruning and/or fruit-thinning can be used to adjust the fruit load of each individual plant according to its vegetative vigor [12]. In the literature, there is evidence that the pruning of the main stem and fruit-thinning influence melon (*Cucumis melo* L.) [13] and watermelon quality [14]. However, the information about the effects of pruning and fruit-thinning on grafted watermelon is very limited. Therefore, this study aimed to evaluate the effects of pruning and fruit-thinning on the postharvest quality of grafted watermelon fruit after a marketing simulation of four days of storage at 22 °C.

Pumpkin rootstock is associated with very strong growth vigor, which can promote rapid canopy growth and the rapid growth of lateral stems, and thereby increase the number of fruits on each plant and the total yield [1,15]. However, this may affect the overall fruit quality, as too many fruits that serve as very strong sinks will not develop, ripen and mature in the most optimal way. Pruning and thinning are used to achieve a balance between vegetative and reproductive growth, to reduce competition between fruits (sink) and canopy (source) and ensure the regular production of fruit and maximize fruit quality [16,17]. As shown by our results, the average number of marketable fruits (per m^2) was not affected by the pruning or thinning of grafted plants. Similar results were reported from a study of melon (*C. melo* L.), in which main-stem pruning and fruit-thinning did not affect production characteristics (i.e., number of fruits per plant, average fruit weight and yield), but did affect some physical-chemical parameters during storage [7]. From the fruit-quality perspective, thinning young fruits can affect the balance between the source (canopy) and sink (fruit) by removing extra fruits (sinks), which allows the remaining fruit to ripen and mature in a more optimal way and exhibit better internal and sensorial qualities after the marketing simulation.

Our two-year study showed that the combination of rootstock and scion is important in relation to fruit-thinning and pruning. Specifically, the combination of Nurit rootstock and fruit-thinning was associated with better fruit quality after harvest. It is possible that the Nurit rootstock is more compatible with the 1262 scion (variety) than the TZ rootstock is, as reported for different cucurbitaceous grafted vegetables and in the context of the effects of different rootstock–scion combinations on yield and fruit quality [15,18]. We also found that thinning small fruits a month after fruit-setting had a greater influence on postharvest fruit quality than pruning did. However, not all of the quality parameters that were evaluated in our study were significantly affected by fruit-thinning.

Thinning may also position the remaining fruit on the plant in a more efficient way, as reported for melon fruit [16,19]. Another possibility is that the leaf area-to-number of fruit ratio is improved by fruit-thinning, as reported by Frioni et al. [20] for grapes (*Vitis vinifera*). In melons, pruning the main stem promotes the rapid growth of lateral stems. A subsequent increase in the photosynthetic area of the plant allows for the production of larger fruits with high soluble-solids content [21]. It is, therefore, possible that in the case of watermelon, thinning had a stronger effect on the distribution of photoassimilates, which improved some of the internal quality parameters of the harvested fruit.

5. Conclusions

Pruning and fruit thinning can influence the yield and quality of harvested fruit. Our two year study aimed to evaluate the effects of pruning and fruit-thinning on the postharvest quality of watermelons that were grown on plants that included two different rootstocks and which were stored for four days at 22 °C (local marketing simulation). Fruit quality was affected mainly by Nurit rootstock in combination with fruit-thinning and was less affected by pruning. However, not all of the internal and nutritional quality parameters were significantly affected by this combined grafting + thinning treatment. Since watermelon fruit quality is significantly affected by the growing region and the rootstock-scion combination, regardless of rootstock vigor [22], it is very important to develop specific pruning and/or thinning practices for each growing region and rootstock–scion combination.

Author Contributions: Conceptualization: M.Z.-P. was the M.Sc. student and later the research technician who conducted this research and wrote the first draft of the MS. S.A.-T. and D.C. are research technicians in Elazar Fallik’s lab; they conducted and analyzed some of the experiments. M.B. is a research technician in Abraham Gamliel’s lab who analyzed the yield and fruit quality before harvest. A.G. was responsible for setting up, designing and analyzing the field experiment and harvest. E.F. supervised M.Z.-P. during her M.Sc. studies, planned the study and wrote the MS together with A.G. All authors have read and agreed to the published version of the manuscript.

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