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Relationships between Rootstock-Scion Combinations and Growing Regions on Watermelon Fruit Quality

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Abstract: Grafting of vegetable plants is done primarily to reduce the potential for damage caused by soil-borne diseases. Most of the watermelons (*Citrullus*) grown in the Mediterranean Basin, including in Israel, are grafted, mainly on interspecific hybrid pumpkin (*Cucurbita*) rootstocks. Biblical law (Leviticus 19:19) does not allow intergeneric grafting, so in recent years, great efforts have been made in Israel to find or breed watermelon rootstocks. Both interspecific and intergeneric grafting can have negative or positive effects on fruit yield and quality after harvest. The inconsistencies in fruit quality and shelf-life parameters can be attributed to differences in production environments. However, many farmers are grafting and planting the same rootstock-scion combination all over the country, regardless of local soil, water, and climactic conditions. We studied the effect of similar rootstock-scion combinations on watermelon yield and fruit quality in three regions of Israel differing in soil type and altitude. Fruit-quality parameters were evaluated after 4 days at 21 °C (local marketing simulation). Fruit quality was significantly affected, mainly by the growing region, based on factorial analysis, but also by rootstock-scion combination, regardless of rootstock vigor. Therefore, the best rootstock-scion combination needs to be found and adopted for each growing region. Grafting was essential for watermelon crop survival in contaminated soils and improved both plant performance and postharvest fruit quality, but was not a factor in non-contaminated soils.

Keywords: internal quality; postharvest; pumpkin rootstock; sensory; watermelon rootstock

1. Introduction

Sweet dessert watermelons, *Citrullus lanatus* (Thunb.) Matsum. & Nakai, are a widely planted vegetable crop and are much appreciated by consumers the world over [1]. Grafting dessert watermelon cultivars onto disease-resistant rootstocks has become a prerequisite for watermelon production in many areas, especially where intensive cultivation is practiced and soil-borne pathogen populations have increased [2,3]. Most of the dessert watermelons grown in the Mediterranean Basin, including in Israel, are grafted, mainly on interspecific hybrid pumpkin (*Cucurbita*) rootstocks. Biblical law (Leviticus 19:19) prohibits intergeneric grafting, so in recent years, great efforts have been devoted in Israel to finding or breeding watermelon rootstocks, mainly of citron watermelon (*Citrullus amarus* Schrad.) [1]. Grafted plants absorb water and nutrients from the soil more efficiently and retain their vitality for longer periods during the growing season [4]. However, rootstock-scion combinations can affect and alter the final size, yield, and quality of fruits, both immediately postharvest and during prolonged storage. These alterations may be attributed in part to differing production environments and methods, the type of rootstock-scion combinations used, and harvest date [5,6]. Therefore, it is important to evaluate and select suitable scion-rootstock combinations for each particular growth condition created by ecology and the growth cycle, to guarantee high fruit quality [5]. Hence, the purpose of this work was to evaluate the relationship between similar rootstock-scion combinations that were grown in several regions on harvested fruit quality, and to observe the effects of watermelon (*Citrullus*) rootstocks on fruit production and quality.

2. Materials and Methods

2.1. Field Experiments and Plant Materials

The field experiments were conducted in 2017 and 2018 at three locations. The Eden Experiment Station, near Bet She'an (northeastern Israel, Bet She'an Valley, 32°28′162″ N, 35°29′425″ E; Alt: −130 m) has a heavy soil (alcareous serozems). The Newe Ya'ar Research Center (northern Israel, Yizre'el Valley, 32°42′413″ N, 35°11′010″ E; Alt: +119 m) has a heavy grumusol soil (brown rendzinas and pale rendzinas). Qalya (eastern Israel at the northern end of the Dead Sea, 31°45′214″ N, 35°28′622″ E; Alt: −400 m) has a desert soil (Regosols and coarse desert alluvium). The soils at Bet She'an and at Qalya are severely infested with *Macrophomina phaseolina*, the causal agent of charcoal rot and vine decline in many field and vegetable crops [3].

The experiments consisted of three-bed-wide plots (bed width 1.93 m × 15 m long). All three beds were used for data collection. At Qalya, half of the experiment was conducted inside a tunnel covered with a 50-mesh insect-proof net (Ginnegar Ltd., Ginnegar, Israel) to prevent virus infestation. Seedlings were planted 2 m apart, resulting in a plant population equivalent to 2500 plant ha^{-1}. At Bet She'an and Qalya, soil fumigation was conducted prior to planting and treatments were arranged in a randomized complete block design with five replications per treatment. A wide, impermeable Ozgard plastic sheet (Ginnegar Ltd., Ginnegar, Israel) was manually laid over the three beds. Metam sodium (MS, 510 g L^{-1}, Edigan, Agan Ltd., Ashdod, Israel) was injected at a rate of 60 g m^{-2} through polyethylene irrigation drip lines, which were placed under the plastic prior to mulching. The MS was applied in the irrigation water (30 L m^{-2}) 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 experiment was set up in a factorial split-plot design, with five replicates for each treatment. The plants were drip-irrigated and grown as per recommendations for commercial watermelon production in each particular region.

Three commercial *Cucurbita* spp. (*Cucurbita maxima* Duchesne × *Cucurbita moschata* Duchesne) rootstocks were used in this work: 'TZ-148' (Hazera Ltd., Berurim, Israel, strong vigorous growth), 'Nurit' (Hishtil Ltd., Nehalim, Israel, moderate vigorous growth), and 'Tetsukabuto' (Eden Seeds, Ltd., Hazav, Israel, strong vigorous growth) onto which were grafted scions of the dessert watermelon 'Fashion' (seedless, midi-round fruit with dark green skin and red flesh, Bayer Ltd., Hod HaSharon, Israel).

In addition, four experimental watermelon rootstocks, two of citron watermelon (*Citrullus amarus*), one of dessert watermelon (*C. lanatus*), and one of colocynth, *C. colocynthis* (L.) Schrad., were evaluated. These were self- and sib-pollinated progenies of United States plant introductions derived from four countries, PI 482318 (318, Zimbabwe), PI 532819 (819, China), PI 542114 (114, Botswana) and PI 549161 (161, Chad), the first and third being *C. amarus*, the second *C. lanatus*, and the last *C. colocynthis*. Onto them were grafted scions of dessert watermelon No. 1262 (seedless, maxi fruit, oval shape and red flesh, Gadot-Agro Ltd., Giv'at Brenner, Israel). 'Shimshon' rootstock (*Cucurbita maxima* × *Cucurbita moschata*, Hazera Ltd., Berurim, Israel, strong vigorous growth) served as a pumpkin control, while non-grafted plants served as another control.

2.2. Fruit Quality

Fruit quality was evaluated after 4 days at 21 °C and 65–70% relative humidity (RH) (simulation of local marketing). Each treatment consisted of 8 to 10 fruits that were harvested based on withering of the tendril adjacent to the fruit stem, and fruit skin color and ground spot color. Total soluble solids (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 percentage Brix (TSS). Fruit texture and overall taste were evaluated by 6 trained tasters by cutting a 3 × 3 × 3 cm section from the heart of the fruit, as follows: Texture was scored on a scale of 1–3, where 1 = very soft and mealy, 2 = a bit crispy, 3 = very crispy and a bit dry and gummy. Overall taste was scored on a scale of 1–3, 1 = very bad taste with severe bitterness or off-flavor, 2 = reasonable taste and a bit crispy, 3 = excellent taste (sweet, crispy and juicy, no off-flavor or bitterness).

Nutritional parameters that were evaluated were lycopene content, vitamin C, and total antioxidant activity, as follows, for all the fruits in each treatment: Lycopene was extracted and quantified by taking 100 g tissue sample from the heart of fruit, slicing and storing at −80 °C until used. The frozen watermelon tissue was ground with a mortar and pestle. A 5 g duplicated sample was weighed into two glass test tubes that 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 was added to each vial before an additional shaking for 5 min was performed. Vials were then held for 5 min at room temperature for phase separation. Lycopene concentration in the upper hexane layer was quantitated against pure hexane on a Jasco V-550 UV–VIS spectrophotometer at 503 nm using the extinction coefficient of 17.2 × 104 M^{-1} cm^{-1}. The results were obtained as μg 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 milligrams of vitamin C per 100 g fresh weight (FW) of fruit. Antioxidant activity (AOX) was evaluated by decolorization of the 2,2′-azinobis-(3-ethylbenzothiazoline-6-sulphonate) radical ($ABTS^+$ radical). The decolorization test was performed in plastic cuvettes by adding 10 μL of test sample to 1 mL of acidified solution of ABTS+ in ethanol, measuring the optical density at 734 nm after 15 min of incubation at room temperature, and comparing it with that of a blank sample. A 1 mM solution of 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox, a water-soluble derivative of vitamin E) was used as a standard. The antioxidant levels in the samples were determined as Trolox equivalents (TE) according to the formula TE = (A sample − A blank)/(A standard − A blank) × C standard, where A is the absorbance at 734 nm and C is the concentration of Trolox (mmol). To calculate the TE antioxidant capacity (TEAC) per unit weight of plant tissue, we used the formula TEAC (mmol TE/mg) = (TE × V)/(1000 × M), in which V is the final extract volume and M is the amount of tissue extracted.

2.3. Statistical Analysis

Data on fruit quality were taken from 8–10 fruits of uniform size and shape per treatment. All data were subjected to one-way or two-way (among rootstocks, and among grafting and growing region) analysis with a statistical significance set at $P = 0.05$ using the JMP10 Statistical Analysis Software Program (SAS Institute Inc. Cary, NC, USA). In addition, a factorial design was used to apply analysis of variance (ANOVA) to analyze the influence of the region, the grafting, and their interaction on fruit quality at $P = 0.05$.

3. Results

3.1. Pumpkin Rootstock and Growing Region

All the quality parameters that were measured with the watermelon scion 'Fashion' were significantly affected by the rootstock when compared within the growing region, and when compared among the growing regions using the same rootstock. Grafting increased sugar content, and improved texture and overall taste of the fruits compared with non-grafted plants (Table 1).

The highest sugar content obtained at Bet She'an for the 'Fashion'-'Nurit' combination was 12.4%, and the lowest was from the non-grafted 'Fashion', 11.0%. The highest sugar content at Qalya, 12.9%, was obtained from fruits harvested from grafts onto rootstock TZ-148 grown in the tunnel and the lowest at Qalya, 11.0%, was from fruits of non-grafted plants (Table 1).

Rootstock 'Tetsukabuto' significantly improved fruit texture at Bet She'an, as compared with non-grafted. Similar results for texture were obtained from fruits grown inside the tunnel at Qalya.

The overall taste of fruits harvested from grafted plants at Qalya was much better in most of the combinations, compared with the overall taste of fruits harvested from grafted plants at Bet She'an (Table 1). The best taste was found for the 'Nurit' and 'TZ-148' combinations, in tunnel and open fields, respectively, while the worse taste was found at Bet She'an, in fruits from non-grafted plants (Table 1).

Table 1. The influence of growing locality and rootstock-scion combination on fruit quality parameters after 4 days at 21 °C. Means of 10 fruits per treatment.

Scion-Rootstock Combination	Sugar Content (% TSS)			Texture (1–3)			Overall Taste (1–3)		
	Bet She'an	Qalya Open Field	Qalya Tunnel	Bet She'an	Qalya Open Field	Qalya Tunnel	Bet She'an	Qalya Open Field	Qalya Tunnel
Fashion-NG	11.0 Bb *	11.6 Ca	11.0 Cb	1.8 Ba	1.9 Ba	1.8 Ca	1.8 Ba	2.0 Ba	1.9 Ca
Fashion-Nurit	12.4 Aa	12.6 ABa	11.7 BCa	2.0 Ba	2.3 Aa	2.2 BCa	2.1 Ab	2.4 ABab	2.6 Aa
Fashion-TZ148	11.2 Bb	13.3 Aa	12.9 Aa	2.2 ABa	2.3 Aa	2.3 ABa	2.1 Ab	2.6 Aa	2.3 ABab
Fashion-Tetsukabuto	11.7 ABa	12.5 BCa	12.2 ABa	2.4 Ab	2.2 ABab	2.5 Aa	2.2 Aa	2.4 ABa	2.1 BCa

* Different upper-case letters represent significant differences among the grafting treatments within the two locations, and different lower-case letters represent significant differences between the locations, at $P = 0.05$; Total soluble solids (TSS).

3.2. Watermelon Rootstocks

Watermelon rootstocks were grown at two locations: Newe Ya'ar and Bet She'an. The major and significant differences were found in fruit harvested from the latter, while at Newe Ya'ar most of the quality parameters did not differ significantly among fruits harvested from grafted and non-grafted plants (Table 2). However, the quality parameters that were evaluated after 4 days at 21 °C were superior in fruits harvested from Newe Ya'ar to fruits harvested from Bet She'an. In general, the overall quality parameters of fruits harvested from plants grafted onto watermelon rootstocks were better in comparison to the quality parameters in fruits harvested from the 'Shimshon' pumpkin rootstock (Table 2). The highest TSS content at Newe Ya'ar was obtained using rootstocks PI 482318 and PI 532819 (12.9%), while the lowest TSS was found using 'Shimshon' (Table 2). At Bet She'an, the highest TSS was obtained using rootstock PI 532819, while the lowest TSS was measured in fruits from non-grafted plants. No significant differences were found in texture, taste, lycopene, and vitamin C in fruits harvested at Newe Ya'ar, though at Bet She'an significant differences were observed among treatments (rootstocks) (Table 2).

Table 2. The influence of watermelon rootstocks (WM) PI482318 (318), PI549161 (161), PI532819 (819), PI542114 (114), and pumpkin (P) rootstock 'Shimshon' on fruit quality after 4 days at 21 °C, from two growing locations, Newe Ya'ar and Bet She'an. NG: non-grafted control. Means of 8 fruits per treatment.

Rootstock-Scion	TSS (%)		Texture (1–3)		Taste (1–3)		Lycopene [1]		Vitamin C [2]	
	Newe Ya'ar	Bet She'an	Newe Ya'ar	Bet She'an	Newe Ya'ar	Bet She'an	Newe Ya'ar	Bet She'an	Newe Ya'ar	Bet She'an
NG-1262	11.6 Aba *	10.8 Ca	2.1 Aa	1.9 Ba	2.0 Ab	1.8 Ba	59 Aa	40 Aa	13.2 Aa	10.0 ABb
318/WM-1262	12.9 Aa	11.7 ABb	2.0 Aa	2.1 ABa	2.2 Aa	2.0 ABa	63 Aa	38 ABb	14.2 Aa	12.1 Aa
161/WM-1262	12.6 ABa	11.4 BCb	2.2 Aa	2.1 ABa	2.1 Aa	2.1 ABa	57 Aa	40 Ab	14.5 Aa	10.0 ABb
819/WM-1262	12.9 Aa	12.1 Aa	2.1 Aa	2.2 ABa	2.3 Aa	2.2 Aa	59 Aa	34 Bb	13.6 Aa	9.5 Bb
114/WM-1262	12.5 ABa	11.4 BCb	2.1 Aa	2.2 ABa	2.2 Aa	2.1 ABa	66 Aa	40 Ab	13.9 Aa	10.0 ABb
Shimshon-P-1262	11.3 Bb	11.5 ABa	2.3 Aa	2.5 Aa	2.0 Aa	1.7 Bb	58 Aa	34 Bb	12.8 Aa	10.3 ABb

* Different upper-case letters represent significant differences among grafting treatments within regions, and different lower-case letters represent significant differences between the two growing regions at $P = 0.05$. [1] μg/g FW; [2] mg/100 g FW; fresh weight (FW).

3.3. Comparisons Among Growing Regions

Growing region significantly influenced TSS, taste, lycopene, AOX activity, and vitamin C content (Table 3). No significant differences were found between the growing systems (open field vs. tunnel) at Qalya. TSS content in fruits harvested at Qalya was significantly higher than at Bet She'an using pumpkin rootstocks, while TSS content was significantly higher in fruits harvested from Newe Ya'ar than from Bet She'an using watermelon rootstocks. Texture was not affected by growing region and rootstock-scion combination. Fruits that were harvested at Qalya were significantly tastier than fruits harvested at Bet She'an and, likewise, fruits harvested at Newe Ya'ar were tastier than fruits harvested at Bet She'an. Lycopene content of fruits was significantly influenced by watermelon rootstocks, but not in fruits that were harvested from plants grafted onto pumpkin rootstocks. Significant differences were found in AOX activity and vitamin C content among fruits harvested at Qalya and Bet She'an from plants grafted onto pumpkin rootstocks, and in AOX activity among fruits harvested at Newe Ya'ar and Bet She'an from plants grafted onto watermelon rootstocks (Table 3).

Table 3. Comparison among growing localities in relation to fruit quality parameters evaluated after 4 days at 21 °C. Means were analyzed separately for each growing region. The quality parameters for all the grafted treatments were compiled and analyzed by one-way ANOVA.

Scion-Rootstock/Region	TSS–heart (%)	Texture(1–3)	Taste(1–3)	Lycopene [1]	AOX(TEAC) [2]	Vitamin C [3]
Fashion-pumpkin/ Qalya–Open field	12.8 a*	2.3 a	2.5 a	49.3 a	3.5 a	12.8 a
Fashion-pumpkin/ Qalya–Tunnel	12.3 ab	2.3 a	2.3 ab	43.5 a	3.5 a	12.4 a
Fashion-pumpkin/Bet She'an–Open field	11.8 b	2.2 a	2.0 b	40.3 a	2.3 b	9.5 b
1262-watermelon/Newe Ya'ar–Open field	12.7 a	2.2 a	2.2 a	61.3 a	3.7 a	9.7 a
1262-watermelon/Bet She'an–Open field	11.6 b	2.1 a	2.0 b	37.9 b	2.0 b	10.4 a

* Different letters represent significant differences among growing regions and growing method for each rootstock, separately. [1] μg/g FW; [2] TEAC (mmol TE/mg); [3] mg/100 g FW; Antioxidant activity (AOX).

Table 4 shows the influence of each factor, region and grafting treatment, separately, and their interaction on fruit quality. *F* values for most of the quality parameters were much higher in comparisons among regions than among grafting treatments, and their corresponding *P* values were very low. Grafting significantly affected texture and AOX, but had little or no influence on the other quality parameters. However, there were significant interactions between growing region and grafting treatment for all quality parameters, except vitamin C (Table 4).

Table 4. A factorial analysis to evaluate the influence of the region, the grafting, and their interaction on fruit quality after 4 days at 21 °C at $P = 0.05$ (*F* and *p* values).

Quality Parameter	TSS-Heart (%)		Texture (1–3)		Taste (1–3)		Lycopene µg/g FW		AOX mmol TE/mg		Vitamin C mg/100 g FW	
Factor	**F Value**	***p* Value**	**F Value**	***p* Value**	**F Value**	***p* Value**	**F Value**	***p* Value**	**F Value**	***p* Value**	**F Value**	***p* Value**
Region (R)	10.93	0.0002	1.68	NS	14.26	0.0001	3.42	0.076	21.72	0.0001	51.86	0.0001
Grafting (G)	1.86	0.1711	7.41	0.002	2.91	0.0672	1.10	NS	6.32	0.0045	2.44	NS
R × G	7.08	0.0003	4.62	0.004	3.50	0.0163	5.43	0.011	2.91	0.0347	2.05	NS

NS: not significant.

4. Discussion

Grafting of vegetable seedlings is widely used in horticultural crop production for various reasons, such as managing soil-borne diseases and improving crop responses to abiotic and biotic stresses, thereby increasing yield and fruit quality [7]. Yet, many factors such as cultivar, weather, preharvest treatments, and postharvest treatments affect postharvest fruit quality [8]. However, rootstock-scion combination and compatibility [9], as well as cultivation method and growing season [5], can affect the harvested fruit quality positively or negatively [7,10].

In this work, we have shown that the growing region plays an important role in influencing fruit quality (Table 4) after harvest and consumer acceptance, in spite of the fact that identical combinations of rootstock and scion were used and fruits were harvested based on similar criteria, including fruit size and color, tendril and stem dryness, ground color, or days from anthesis. The differences in fruit quality across growing regions could have resulted from various factors affecting seedling establishment and growth performance in the field. Varying weather conditions, day and night temperatures, soil type and fertility, and irrigation quality and quantity are known to affect fruit quality [11,12]. We observed significant interactions between growing region and grafting treatment (Table 4). Thus, it seems quite plausible that planting a specific and unique rootstock-scion combination in a given growing region enables the grafted plant to better cope with biotic and abiotic stresses, resulting in improved postharvest fruit quality [13,14]. In addition, it is also quite possible that the optimal combination of grafted plant and growing region benefits from improved plant growth and development, and therefore fruit quality, due to better water, mineral, and long-distance signal-molecule translocation from the rootstock to the scion and fruit, or by different gene expression that contributes to better compatibility [15,16].

In agricultural production, a lack of compatibility between scions and rootstocks often occurs, which results in low survival rates, weak growth, and an adverse effect on fruit quality, all of which lead to serious economic losses. Graft compatibility directly influences the efficiency of grafting, therefore, good graft compatibility between the rootstock and scion is a prerequisite for grafting. However, the underlying causes of graft incompatibility are currently unknown. The survival rate of compatible graft combinations of watermelon was significantly higher than that of incompatible combinations [9]. Graft incompatibility increases with taxonomic distance, but predicting compatibility is not always easy. Most intraspecific grafts and interspecific grafts (from within the same genus) are compatible [15]. Intergeneric grafts are rarely compatible, except within the Solanaceae and Cucurbitaceae, in which compatibility between different genera is exploited in commercial grafting. Despite its importance in horticulture, little is known about the mechanisms that cause graft compatibility/incompatibility [16].

Pumpkins (genus *Cucurbita*) and watermelons (genus *Citrullus*) are both members of the Cucurbitaceae. *Cucurbita* rootstocks are the most commonly used for grafted watermelon cultivation. Grafting watermelon plants onto pumpkin rootstocks can compensate for the shortcomings of their fragile roots, enhancing their resistance to adverse environmental conditions, promoting vigorous growth, and ultimately improving the yield and quality of the watermelons produced. However, not all grafted horticultural crops possess these favorable traits [15,17]. The four *Citrullus* rootstocks that we have used in this work, particularly the citron watermelon PI 482318, rendered improved fruit quality to their dessert watermelon scions after 4 days at 21 °C when compared to that of fruits harvested from plants on the 'Shimshon' pumpkin rootstock (Table 2). It is highly likely that wild and cultivated citron watermelon genotypes can become valuable rootstocks for dessert watermelon production, because they have good grafting compatibility and have no negative impact on fruit quality when compared to other rootstocks, such as some cultivars of bottle gourd (genus *Lagenaria*) and pumpkin, as reported by Nawaz et al. [18,19]. Furthermore, the potential use of wild citron watermelon rootstocks was reported by Thies et al. [20]. These wild citron watermelon rootstocks were reported to possess useful resistance to nematodes in the field, due to larger and excellent fibrous root systems that give the ability of a host plant to tolerate attack by pathogens, and at the same time, to improve the fruit yield.

Grafting was essential for crop survival in the contaminated soils at Qalya and Bet She'an, and improved both plant performance and postharvest fruit quality, but was not a factor in the non-contaminated soils at Newe Ya'ar, as shown in Table 2. Because grafted seedlings have an associated increase in cost and do not produce increased yields on non-contaminated media [21], grafting in these optimized farming systems does not offer an advantage in the absence of soil-borne pathogens or other stress factors that interfere with watermelon production [22].

5. Conclusions

We have provided new insights into the problems of using similar rootstock-scion combinations across growing regions [23], and how the growing region can affect more strongly fruit quality more than the grafting itself. However, the interaction between the growing region and grafting plays an important part in determining fruit quality (Table 4). Such tests are, therefore, helpful in assisting the selection or breeding of rootstock-scion combinations, in order to maintain consumer satisfaction and improve our understanding of the relative contributions of various rootstock-scion combinations, across environments, to various fruit-quality components. It is important to evaluate and select suitable rootstock-scion combinations adapted to particular environments and growing conditions in order to ensure high fruit quality [5,24]. Therefore, in the near future, "custom-made-farming" should be considered before planting grafted watermelons, or other fruits and vegetables in a specific growing region. In addition, we have proved again that grafting is essential in contaminated soils, but not necessarily beneficial in media free of soil-borne pathogens.

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