Fruit Volatiles, Quality, and Yield of Watermelon as Affected by Grafting

S. A. Petropoulos[1*], C. Olympios[2], A. Ropokis[2], G. Vlachou[2], G. Ntatsi[2], A. Paraskevopoulos[3], and H. C. Passam[2]

ABSTRACT

The aim of the present study was to examine the effect of grafting of watermelon hybrids 'Obla F_1' and 'Vanessa F_1' on to *Cucurbita maxima* × *Cucurbita moschata* rootstock TZ 148 and *Lagenaria* sp. rootstock 'Dias F_1', on the volatiles and yield of fruit and the plant growth. Fruit volatiles analysis showed the presence of two aldehydes, namely (E)-2-nonenal and (E,Z)-2,6-nonadien-1-al, with (E)-2-nonenal being present at higher concentrations in grafted than in un-grafted plants. Grafted plants had also higher growth rate, total yield, and fruit number than un-grafted plants, whereas the percent dry matter of leaves and shoots was higher in ungrafted plants. No differences were observed for mean fruit weight, fruit shape, and rind thickness. Fruit from grafted plants had more compact flesh and less acid fruit juice than fruit from ungrafted plants. Fruit volatile components differed between ungrafted and grafted plants. With regards to sugar content, no significant differences between grafted and ungrafted plants were observed, except in the case of 'Obla F_1' hybrids. Sodium concentration of plant tissues and fruit was higher in 'Obla F_1' ungrafted plants, as well as carotenoid, lycopene, and vitamin C content in fruit, but only in the second year. In conclusion, rootstock-scion combination implemented in the present study affected plant growth and fruit yield and quality, rendering the choice of rootstocks and scions of major importance in order to achieve the highest yield and quality of watermelon fruit.

Keywords: *Citrullus vulgaris* L., Obla F_1 hybrid, Vanessa F_1 hybrid, Volatiles profile.

INTRODUCTION

Watermelon is a warm-season crop cultivated throughout the world. The main producing countries are China, Turkey, and Iran, which produce almost 78% of the total world production (Shahbazi *et al.,* 2010). However, the intensive cultivation of watermelon within the major productive regions over recent decades and the declining availability of fresh water (Mousavi *et al.,* 2009) have resulted in a gradual deterioration of arable land, mostly due to an increase of soil-borne diseases and

downgrading of soil properties and fertility. Therefore, the main means for overcoming problems of soil deterioration and soil-borne diseases is the implement of grafting desired scions of watermelon on to resistant rootstocks (Pofu *et al.*, 2012).

Grafting affects growth, whereas under low temperatures it can ensure higher yields than in ungrafted plants (Sakata *et al.*, 2007; Davis *et al.*, 2008a). Improved growth has been related with the better development of root system of watermelon plants grafted on to *Cucurbita* species, compared to ungrafted plants, resulting in enhanced water and

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[1] Laboratory of Vegetable Production, University of Thessaly, Fytokoy Str., 38446, N. Ionia, Magnisia, Greece.
[*] Corresponding author email:
[2] Laboratory of Vegetable Production, Agricultural University of Athens, Greece.
[3] Department of Agriculture, Faculty of Agriculture, Kyparissia, Greece.

nutrient assimilation (Bletsos, 2005). A beneficial effect of grafting on total yield was also reported for watermelon cv. 'Crimson Sweet', 'Crimson Tide', 'Crispy' and 'Ingrid' grafted on to various rootstocks (Alan *et al.*, 2007; Alexopoulos *et al.*, 2007; Proietti *et al.*, 2008; Karaca *et al.*, 2012).

According to many studies, rootstock-scion combination may also affect fruit quality features, such as pH, sugar content, carotenoid content, chemical composition of the fruit, flesh colour and flavour (Perkins-Veazie *et al.*, 2007; Davis *et al.*, 2008b; Bletsos and Passam, 2010; Gisbert *et al.*, 2011; Bekhradi *et al.*, 2011; Petropoulos *et al.*, 2012; Milošević *et al.,* 2013). This effect is mainly attributed to a scion-rootstock interaction which influences various plant physiological processes such as nutrient and water uptake and translocation, hormone synthesis, photosynthesis and other metabolic processes (Rouphael *et al.*, 2010).

Regarding fruit aroma, Obando-Ulloa *et al.* (2010) reported that the pleasant odor in cucumber has been attributed to (E,Z)-2,6-nonadien-1-al, whereas (E)-2-nonenal, 2-hexenal and three other saturated aldehydes contribute secondarily to overall flavour (Beaulieu and Grimm, 2001; Beaulieu and Baldwin, 2002; Palma-Harris *et al.*, 2002; Beaulieu, 2005). Palma-Harris *et al.* (2002) have also reported that humans can detect differences in the intensity of cucumber flavour due to the presence of (E,Z)-2,6-nonadien-1-al and (E)-2-nonenal. However, even aldehydes that are not easily detectable or have a low human detection threshold could play an important role in the flavour of various vegetables (Obando-Ulloa *et al.*, 2010).

Rootstock-scion combination may affect the mineral concentration of aerial plant parts due to differences of physical characteristics of the root system of grafted plants, which allow for better water and mineral nutrients uptake, compared to ungrafted plants (Rouphael *et al.*, 2008). Mineral concentration of plants is strongly related with plant growth and development, as well as with enzymatic activities responsible for fruit quality features (lycopene, carotenoids, vitamin C, TA, TSS); therefore, improved mineral uptake of grafted plants is associated with better plant development, higher yield and better fruit quality. Moreover, mineral composition of aerial parts may be affected by both grafting implementation and rootstock-scion combination, regarding either macro or micronutrients, by improving nutrient and water uptake of grafted plants or by eliminating toxicity effects of microelements (Rouphael *et al.*, 2008)

The aim of the this study was to evaluate, for the first time, the effect of rootstock-scion combination of watermelon plants on fruit volatiles profile, as well as to evaluate the effect of grafting on plant growth and development, yield, and fruit quality.

MATERIALS AND METHODS

Plant Material

The experiment was carried out over two consecutive years (2009-2010) at the region of Filiatra, Greece ((latitude 38° 8′ 58″, longitude 21° 34′ 28″). In the first year, the hybrids of 'Obla F$_1$' and 'Vanessa F$_1$' were used as scions, grafted on to the rootstock TZ 148 (*Cucurbita maxima* x *C. moschata*), while scions of 'Vanessa F$_1$' were also grafted onto 'Dias F$_1$' (*Lagenaria* sp.) rootstock. Seeds of both scions and rootstocks were sown in seed trays on 5th and 6th January, respectively, and those of ungrafted plants on 14th January. Grafting took place on 30th January using the tongue-approach technique (Oda, 1999) followed by field transplanting on 8th March, for both grafted and ungrafted plants.

In the second year, the scion 'Obla F$_1$' was grafted on to TZ 148 rootstock (*Cucurbita maxima* x *C. moschata*). Seeds of the scion were sown in seed trays on 6th January and those of ungrafted plants on 16th January. Seeds of the rootstocks were sown one week later than those of the scions (14th January). Grafting took place on 29th January using the

same technique as above, while transplanting to the field for both grafted and ungrafted plants was carried out on 9th March. A double row planting system was implemented in both years, with 2.2×1.0 m distances within each pair of rows and 2.0 m distance between the pairs (3,600 plants ha⁻¹). Irrigation and crop management (fertilization, weed and pest control) were carried out according to standard cultivation practices. The climate conditions throughout the two growing seasons are presented in Table 1. Regarding the soil properties, soil texture was SLC, organic matter content was 1.54%, pH=7.78 and *EC= 1.23* mS cm⁻¹. Base dressing was applied with row placement at a rate of 93 kg ha⁻¹ of N, 100 kg ha⁻¹ of P (P_2O_5), 180 kg ha⁻¹ of K (K_2O), 60 kg ha⁻¹ of Mg (MgO) and 252 kg ha⁻¹ of S (SO_3).

Analytical Methodology

During cultivation and until harvest time, measurements from three plants from each block and each treatment were recorded *in situ* for the number of lateral shoots, shoot length, number of leaves of the main and lateral shoots, leaf area and fresh and dry weight of shoots, leaves, and roots. Leaf area was measured using a LI-COR area meter (Model 3100, Nebraska USA). On the day of harvest, eight plants from each block and each treatment were randomly selected for further analysis of the mineral concentration of shoots and leaves. Samples of plant tissues were dried in a forced-air oven at 72°C to constant weight, ground to powder, subjected to dry ashing and extracted with 1N HCl to determine Ca, Mg, Fe, Mn, Zn, and Cu concentration by atomic absorption spectrophotometry (Perkin Elmer 1100B, Waltham, MA) and K concentration by flame photometry (Sherwood Model 410, Cambridge, UK).

Fruits were harvested at visual maturity and according to market standards fruit size and weight (3-4 kg for small fruit varieties and 8-10 kg for large fruit varieties, yellowish skin colour of the underside, stretched skin stripes, etc.) on 22nd July and 26th July, in the first and second year, respectively, whereas immature or unmarketable fruits on the day of the harvest were discarded. After harvest, the fruit weight and fruit shape (Shape Index expressed by the ratio of longitudinal to equatorial length) were measured *in situ*, using five fruits per treatment randomly selected for postharvest measurements.

Each fruit was bisected equatorially and rind width was measured. Flesh firmness was recorded with a flat bottom probe (d=12 mm and 2 mm width) using a Chatillon DPP 25 kg force gauge mounted on a model LTS manual test stand (John Chatillon and Sons, Greensboro, NC) and applied to sections (5×3 cm) in the center of the flesh. Approximately 150 g from the central flesh of each fruit was reduced to a pulp and the EC and pH were measured. Total soluble

Table 1. Monthly average of mean, maximum, and minimum air temperature and relative humidity during the two growing seasons.

Months	T_{mean} (°C) [a]		T_{max} (°C) [a]		T_{min} (°C) [a]		RH (%) [b]	
	2009	2010	2009	2010	2009	2010	2009	2010
January	9.8	6.2	17.6	13.5	0.6	-2.0	83.7	29.4
February	7.4	8.4	18.5	15.2	-0.5	-1.0	73.1	45.2
March	9.8	10.5	23.7	17.0	1.4	-1.0	70.2	65.2
April	14.1	15.1	27.0	25.1	8.3	7.3	70.3	53.6
May	18.7	18.2	30.7	32.3	8.6	10.0	61.6	58.7
June	22.3	21.6	33.4	37.0	13.9	12.6	59.6	58.8
July	25.0	24.7	38.2	34.5	16.5	15.9	54.1	55.3

[a] Temperature, [b] Relative Humidity

solids (°Brix) within the fruit flesh were measured with the aid of a hand refractometer (Schmidt and Haensch HR 32 B, Berlin, Germany). The fruit acidity (Titratable Acid, TA) was determined in 10 mL of juice by potentiometric titration with 0.02M NaOH to pH 8.1. Vitamin C content was determined by the 2,6-dichloroindophenol (DCIP) method (Arya *et al.*, 2000). Lycopene and carotenoid content were estimated using previously described methods (Davis *et al.* 2003; Davis *et al.* 2007). Fruit flesh color was determined by a Minolta CR-300 Chromatometer (Minolta, New Jersey, USA). A portion of fruit flesh was dried in a forced-air oven at 72°C for 72 hours for dry weight measurements. The mineral concentration of the flesh was determined as previously described for leaves and roots.

Sugar extraction was carried out using a standard procedure (Vemmos 1999). Sugar content was determined by HPLC using a Varian 9010 integrator (Varian Inc., Palo Alto, USA), a 250×4.6 mm Supercosil LC-NH2 column and eluting with a mixture of Acetonitrile and HPLC water (75:25 by volume, respectively) at a flow rate of 1 ml min^{-1}. Peaks were quantified by using a refractive index detector (ERC-7511, Erma Inc., Tokyo, Japan).

For fruit volatiles extraction, samples were taken from the center of the flesh of each fruit (cubic segments of 5×5 cm) and extraction was carried out manually with the implement of the head space technique (Solid Phase Micro Extraction) using 1-cm 50/30 carboxen divinylbenzene polydimethylsiloxane (carboxen/DVB/PDMS) 100 μm SPME fibers (Superlco, Inc., Bellefonte, PA), as previously described by Beaulieu and Lea (2006) and volatile compounds were analyzed by gas chromatography using an Agilent 6890NII GC (Agilent Technologies Inc., Santa Clara, USA) equipped with an Agilent 5973i MS detector and an SLB-5ms capillary column (30 m×0.25mm, film thickness 0.25 μm) in the electron impact mode (70eV). GC-MS analysis conditions

were according to Beaulieu and Lea (2006). The identification of components was based on the comparison of their GC retention time indices and mass spectra with spectral data from the Mass Spectra Library NBS75K library data of the GC/MS system and literature data (Adams, 2001), as well as with standard compounds when possible. The principal components of the essential oil extracts were quantified by external standardization using benzothiophene.

Statistical Analysis

In both years, the layout of the experimental design was completely randomized blocks, with each block consisting of two rows per treatment (10 plants per row and 20 plants in total for each treatment and replicate) and replicated six times in both years (600 plants and 240 plants in total for years 1 and 2, respectively). Statistical analysis was carried out with the aid of the Statgraphics 5.1.plus statistical package (Statistical Graphics Corporation) and Microsoft Excel 2007 (Microsoft Corporation). Data were evaluated by one-way analysis of variance for the main effect, whereas the means of values were compared by the Least Significant Difference (LSD) test (P= 0.05).

RESULTS

The statistical analysis of the data showed no significant interaction between the grafting treatments and the year of experiment, as well as no significant effect of the year of experiment as a main effect.

Young plants of 'Obla F_1' hybrids grafted on to TZ 148 rootstocks had better development at five weeks after transplanting in the second year, compared to ungrafted plants (Table 2), with similar results in the first year (data not shown). Grafted plants formed more and longer 2nd order lateral shoots than ungrafted plants, while leaf area for both the 1st and 2nd order

lateral shoots and number of leaves of 2nd order lateral shoots were higher in the grafted plants. Similarly, the total dry matter of grafted plants was higher than that of ungrafted plants, whereas no differences in the dry weight ratio of each plant part in relation to the total dry weight were observed between grafted and ungrafted plants (Table 2, Figure 1). The higher dry mass indicates higher plant development and, consequently, higher yield in the second year (75% increase in total fruit yield and 77% increase in fruit number per hectare) for grafted plants of 'Obla F_1' compared to ungrafted plants, without significant differences in fruit shape and fruit mean weight (Table 3), with similar results in the first year (data not shown).

Fruit flesh color was significantly affected by grafting in the case of 'Vanessa F_1', with grafted plants being slightly yellowish in comparison to ungrafted plants, regardless of rootstock, whereas the color of 'Obla F_1' fruit was not affected by grafting (data not shown), indicating that fruit flesh color mostly depended on rootstock-scion combination.

Rootstock-scion combination decreased the TA (by 38.89% only in the first year), Vitamin C, carotenoid, and lycopene content (by about 14.18, 18.47, and 22.32%, respectively, only in the second year), and increased the flesh firmness (40.80 and 69.15% in the first and second year, respectively) whereas rind thickness was not affected by grafting (Table 4). Similar results were also found for 'Vanessa F_1' hybrids (data not shown), indicating that fruit quality is a rootstock-scion combination dependent trait.

The total sugar content was not affected by grafting in either 'Obla F_1' or 'Vanessa F_1' plants. In addition, sugar analysis showed no significant differences between grafted and ungrafted plants in the case of 'Obla F_1' in both years, whereas 'Vanessa F_1' grafted onto *Lagenaria* sp. rootstocks had a higher sucrose content than ungrafted plants and those grafted on to TZ 148 rootstocks (63 and 70%, respectively) (Table 5).

Fruit volatiles analysis showed the presence of two aldehydes, namely, (E)-2-nonenal (CAS 60784-31-8) and (E,Z)-2,6-nonadien-1-al (CAS 557-48-2) (Table 6), described as having a cucumber-like odor (www.thegoodscentscompany.com;

Table 2. Morphological parameters of ungrafted and grafted plants of Obla F_1 in 2010, five weeks after field transplantation.[a]

Treatment	MS length (cm)	Leaf number (MS)	Leaf area (MS) (cm^2)	1st order LS number	Length of 1st order LS (cm)	2nd order LS number
Obla F_1 (U)	108.5 a	25.0 a	1108.5 a	4.2 a	62.2 a	1.0 b
Obla F_1×TZ 148	150.7 a	32.3 a	1820.6 a	5.3 a	79.3 a	9.3 a
Treatment	Length of 2nd order LS (cm)	Leaf number (1st order LS)	Leaf area (1st order LS) (Plant cm^{-2})	Leaf number (2nd order LS)	Leaf area (2nd order LS) (Plant cm^{-2})	DM of MS (%)
Obla F_1 (U)	16.0 b	41.5 a	1663.7 b	4.0 b	46.2 b	88.6 b
Obla F_1×TZ 148	41.2 a	53.0 a	3909.2 a	32.7 a	1201.2 a	90.6 a
Treatment	DM of MS leaves (%)	DM of roots (%)	DM of 1st order LS (%)	DM of 1st order LS leaves (%)	DM of 2nd order LS (%)	DM of 2nd order LS leaves (%)
Obla F_1 (U)	85.9 b	84.6 b	89.5 b	86.5 b	88.9 b	84.2 b
Obla F_1×TZ 148	88.6 a	88.6 a	91.3 a	88.6 a	91.9 a	88.3 a

[a] Mean comparison of means at the same column was carried out by Least Significant Test (P= 0.05). Means with the same letter are not significantly different. MS: Main Stem; LS: Lateral Shoots; DM: Dry Matter and, Treatments abbreviations: U (Ungrafted).
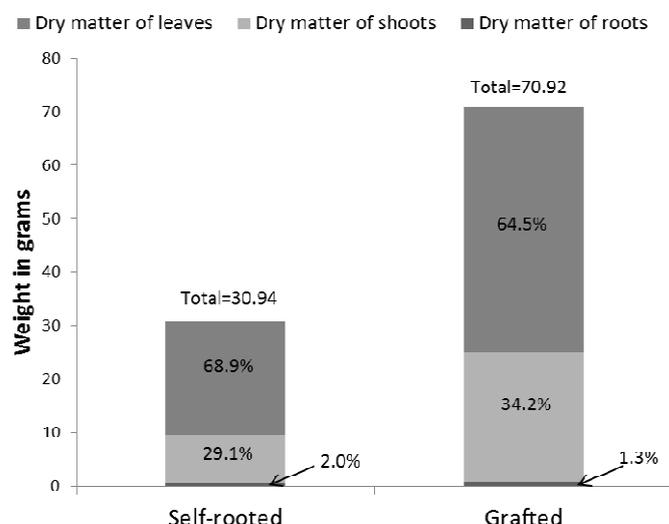
Figure 1. Dry matter of leaves, shoots, and roots of Obla F_1 hybrids (ungrafted and grfated on to TZ-148 rootstocks) at the stage of fruit harvest expressed in grams and their ratio in relation to the total dry weight.

Table 3. Yield parameters for Obla F_1 plants cultivated in the second year (2010).[a]

Treatment	Total yield (Kg ha^{-1})	Fruit number (ha$^{-1)}$	Mean fruit weight (Kg)	Shape Index
Obla F_1 (U)	50233 b	7867 b	6.4 a	1.15 a
Obla F_1×TZ 148	88008 a	13972 a	6.3 a	1.16 a

[a] Mean comparison was carried out by Least Significant Test (P= 0.05). Means with the same letter are not significantly different. Treatments abbreviations: U (Ungrafted).

Table 4. Fruit quality parameters of watermelon hybrids Obla F_1 (OB), either ungrafted or grafted plants on to TZ 148 rootstocks.[a]

Year 1					
Treatment	TA	DM (%)	Vit. C (mg Kg^{-1})	TSS (Brix°)	*EC* (dS m^{-1})
Obla F_1 (U)	0.18 a	7.9 a	56.1 a	11.08 a	3.2 a
Obla F_1×TZ 148	0.11 b	8.4 a	59.6 a	10.50 a	3.6 a
Treatment	FF (N)	RT (cm)	Carotenoids (mg Kg^{-1})	Lycopene (mg Kg^{-1})	pH
Obla F_1 (U)	17.4 b	1.38 a	62.2 a	20.4 a	5.4 a
Obla F_1×TZ 148	24.5 a	1.34 a	56.6 a	19.3 a	5.3 a
Year 2					
Treatment	TA	DM (%)	Vit. C (mg Kg^{-1})	TSS (Brix°)	*EC* (dS m^{-1})
Obla F_1 (U)	0.08 a	12.7 a	12.7 a	11.32 a	3.1 a
Obla F_1×TZ 148	0.08 a	10.9 b	10.9 b	10.32 a	3.1 a
Treatment	FF (N)	RT (cm)	Carotenoids (mg Kg^{-1})	Lycopene (mg Kg^{-1})	pH
Obla F_1 (U)	18.8 b	1.30 a	47.1 a	22.4 a	5.2 a
Obla F_1×TZ 148	31.8 a	1.14 a	38.4 b	17.4 b	5.1 a

[a] Mean comparison was carried out by Least Significant Test (P= 0.05). Means with the same letter are not significantly different. DM: Dry Matter; RT: Rind Thickness; TA: Expressed in grams of citric acid per 100 ml of fruit juice; FF: Flesh Firmness and, Treatments abbreviations: U (Ungrafted).

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Table 5. Sugar content in fruit flesh in relation to grafting and rootstock-scion combination expressed in g kg^{-1}.[a]

Treatment	First year experiment			Second year experiment		
	Fructose	Glucose	Sucrose	Fructose	Glucose	Sucrose
Obla F$_1$ (U)	33.5 a	12.0 a	18.7 a	22.5 a	6.5 a	18.8 a
Obla F$_1$×TZ 148	30.2 a	10.0 a	19.2 a	26.3 a	6.9 a	16.7 a
Vanessa F$_1$ (U)	34.6 a	10.2 a	28.1 b			
Vanessa F$_1$×Dias F$_1$	26.1 a	7.2 a	45.7 a			
Vanessa F$_1$ ×TZ 148	28.8 a	8.9 a	26.8 b			

[a] Mean values in the same column and for the same hybrid followed by different letters are significantly different by Least Significant Test (P= 0.05). Treatments abbreviations: U (Ungrafted).

Table 6. The main volatile components of grafted and ungrafted plants of Obla F$_1$ (OB) and Vanessa F$_1$ (VAN) hybrids, recovered via SPME GC-MS, expressed in µg kg^{-1} of fresh fruit.[a]

RI[a]	Component	Obla F$_1$		Vanessa F$_1$		
		U	Obla F$_1$×TZ 148	U	Vanessa F$_1$×Dias F$_1$	Vanessa F$_1$×TZ 148
1003	(Z)-6-nonenal	2.82b	7.35a	0.40b	1.93a	0.58b
1022	Nonanal	2.43b	3.38a	0.59b	1.94a	0.60b
1167	(E,Z)-2,6-nonadienal	17.83b	43.21a	5.09b	25.26a	5.51b
1178	(Z,Z)-3,6-nonadien-1-ol	3.69b	9.10a	0.80c	11.28a	3.30b
1200	(E)-2-nonenal	0.71b	7.36a	tr	0.59a	0.54a
1531	Unidentified	2.27b	9.57a	1.52c	4.84a	2.87b
1781	Unidentified	0.31b	1.82a	0.45c	1.20a	0.85b

[a] RIs calculated on SLB-5 ms column against n-alkanes. Mean values in the same row and for the same hybrid followed by different letters are significantly different by Least Significant Test (P= 0.05). tr: Traces (< 0.01 µg Kg^{-1} of fresh fruit); RI: Retention Index, Treatments abbreviations: U (Ungrafted).

www.flavornet.org) and being responsible for the fruit-flavour volatiles attributes of cucumbers. (E)-2-nonenal was present at higher concentrations in grafted than in ungrafted plants, regardless of rootstock-scion combinations. However, regarding the other fruit flesh volatile components, no differences were observed between the ungrafted and plants grafted on to TZ-148 rootstocks in the case of 'Vanessa F$_1$' hybrids (Table 6).

Significant differences in the Na, Mg, and Ca concentrations of some plant tissues and fruit Na concentration of 'Obla F$_1$' were detected (Tables 7 and 8). Except for the Na concentration of the leaves of lateral shoots, Na concentration of ungrafted plant tissues were higher than grafted ones. In addition, differences were observed in the Mg and Ca concentration of lateral shoot leaves and the

Ca concentration of the main stem, with grafted plants having a higher concentration than ungrafted plants (Table 8). In the case of 'Vanessa F$_1$', the mineral concentration of ungrafted plants was higher than that of plants grafted on to *Lagenaria* sp. for all elements examined in the present experiment, whereas no differences were observed between grafted plants regardless of rootstock-scion combination (Table 7).

DISCUSSION

Grafted plants had better development and higher yield than ungrafted plants. In previous reports, the effect of grafting on 10 different rootstocks (Yetisir and Sari, 2003), 72 *Lagenaria siceraria* genotypes (Yetisir *et al.*, 2007), and 21 bottle gourds (Karaca *et*

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Table 7. Minerals concentration in fruit of watermelon Vanessa F_1 and Obla F_1 plants cultivated in the first year, either ungrafted or grafted, onto rootstock TZ 148 (*Cucurbita moschata* x *C. maxima*), expressed in mmol g^{-1}.[a]

Treatment	Na	Mg	K	Ca	Zn	Mn	Fe
Vanessa F_1×Dias F_1	0.012 b	0.014 b	0.430 b	0.042 b	0.027 b	0.049 b	0.855 b
Vanessa F_1× TZ 148	0.016 b	0.018 ab	0.517 ab	0.048 b	0.028 ab	0.063 ab	1.051 ab
Vanessa F_1 (U)	0.033 a	0.019 a	0.563 a	0.091 a	0.033 a	0.067 a	1.452 a
Obla F_1×TZ 148	0.013 b	0.016 a	0.45 a	0.034 a	0.017 a	0.056 a	0.867 a
Obla F_1 (U)	0.027 a	0.018 a	0.54 a	0.051 a	0.017 a	0.079 a	1.076 a

[a] Mean values in the same column and for the same hybrid followed by different letters are significantly different by Least Significant Test (P= 0.05). Treatments abbreviations: U (Ungrafted).

Table 8. Mineral concentration of shoots and leaves of watermelon Obla F_1 plants in year 2, either ungrafted or grafted onto rootstock TZ 148 (*Cucurbita moschata* ×*C. maxima*), expressed in mmol g^{-1}.[a]

Plant tissue	Treatment	Na	Mg	K	Ca	Zn	Mn	Fe
Leaves (MS)	G	0.012 b	0.031 a	0.494 a	0.660 a	0.064 a	0.696 a	1.358 a
	U	0.021 a	0.030 a	0.595 a	0.708 a	0.078 a	1.040 a	1.754 a
Leaves (LS)	G	0.014 a	0.029 a	0.588 a	0.610 a	0.141 a	0.718 a	1.793 a
	U	0.018 a	0.023 b	0.575 a	0.429 b	0.053 a	0.751 a	1.979 a
MS	G	0.012 b	0.023 a	0.921 a	0.232 a	0.059 a	0.437 a	1.794 a
	U	0.034 a	0.019 a	0.850 a	0.176 b	0.106 a	0.454 a	1.886 a
LS	G	0.010 b	0.019 a	0.349 a	0.177 a	0.041 a	0.349 a	1.311 a
	U	0.026 a	0.016 a	0.400 a	0.128 a	0.061 a	0.400 a	1.767 a

[a] Mean values in the same column and for the same plant tissue followed by different letters are significantly different by Least Significant Test (P= 0.05). Treatments abbreviations: MS (Main Stem); LS (Lateral Shoots); G (Grafted), U (Ungrafted).

al., 2012) on the growth of watermelon cv. 'Crimson Tide' was studied and grafted plants had in general longer roots and main stems, higher dry weight, more leaves and higher yield, especially when the rootstock was *Lagenaria siceraria*. Grafting watermelon *cv.* 'Top Yield' on to *Lagenaria siceraria* resulted in larger main stems and more lateral shoots than ungrafted plants (Salam *et al.*, 2002).

Salam *et al.* (2002) also reported higher yield for grafted watermelon plants, mainly due to the formation of more and larger fruit than ungrafted plants. Yetisir and Sari (2003) reported an increase of fruit flesh firmness in watermelon plants grafted on to *Lagenaria* sp. and interspecific hybrids of *Cucurbita moschata* × *C. maxima*

rootstocks. In other studies, grafted plants of watermelon *cv.* 'Sugar Baby' had a higher total leaf area and plant dry weight and 200% higher yield in comparison with ungrafted plants, especially when the rootstock was the hybrid RS-841 (*C. moschata* x *C. maxima*) (Chouka and Jebari, 1999). The beneficial effect of grafting on total yield was also reported for cv. 'Crimson Sweet', 'Crispy' and 'Ingrid' grafted on to various rootstocks (Alan *et al.*, 2007; Alexopoulos *et al.*, 2007; Proietti *et al.*, 2008), as well as on fruit shape index (Yetisir and Sari, 2003; Colla *et al.*, 2006; Alan *et al.*, 2007; Proietti *et al.*, 2008). However, in the case of cv. 'Crimson Sweet', higher yield resulted from larger

fruit size rather than a higher fruit number, as reported in our study.

The differences in plant development and fruit yield could be attributed mainly to the root system functionality, which is better for grafted than ungrafted plants, especially when soil problems are present, allowing for better water and nutrient uptake and, consequently, higher photosynthetic and growth rates compared to ungrafted plants (Ruiz *et al.*, 1997). In contrast, the use of *Cucurbita* sp. rootstocks resulted in lower fruit yield in comparison to ungrafted plants of *cv*. 'Crimson Tide' and plants grafted on to Lagenaria sp. rootstocks (Yetisir and Sari, 2003). However, the use of a different scion in that study indicates that rootstock-scion combination might be more significant for fruit yield than the effect of either scion or rootstock separately.

Regarding fruit color, grafted plants of 'Vanessa F_1' hybrid had lower quality (less intensity of red color) compared to ungrafted plants, whereas no differences were observed in the case of 'Obla F_1' plants. Lopez-Galarza *et al.* (2004) reported a similar effect on fruit color of grafted plants of *cv*. 'Reina de Corazones' ; however, in that experiment, fruit setting of grafted plants was induced by a synthetic cytokinin, CPPU, in comparison to self-pollination for ungrafted plants.

Fruit quality parameters such as TA, flesh firmness, Vitamin C, carotene, and lycopene content were also affected by scion-rootstock combination, as previously reported by Lopez-Galarza *et al.* (2004), Proietti *et al.* (2008) and Davis *et al.* (2008b). Previous reports showed that grafting increased fruit rind thickness (Yetisir *et al.*, 2003; Alexopoulos *et al.*, 2007; Proietti *et al.*, 2008; Turhan *et al.,* 2012), however, different scion-rootstock combinations were implemented in these experiments.

The total fruit sugar content was not affected by grafting implementation. However, differences were observed in sucrose content of the fruit. The results

from the literature are contradictory, reporting either a significant (Salam *et al.*, 2002; Yetisir *et al.*, 2003; Lopez *et al.*, 2004; Liu *et al.*, 2006; Cushman and Huan, 2008; Turhan *et al.,* 2012), or an insignificant effect of grafting (Miguel *et al.*, 2004; Colla *et al.*, 2006; Huitrón-Ramírez *et al.*, 2009) on fruit total sugar content. In addition, no significant differences in glucose, fructose, and sucrose content between grafted and ungrafted plants were reported when watermelon cv. 'Tex' was grown under various salinity regimes (Colla *et al.*, 2006). Such differences could be the result of differentiation in enzyme activity of acid invertase, sucrose synthase, and sucrose phosphate synthase, as well as transmembrane transportation of sugars (Xu *et al.*, 2006), indicating a scion-rootstock dependence.

The volatiles analyses in our study showed similar results with those of numerous seedless watermelon varieties, with (E)-2-nonenal, (E,Z)-2,6-nonadien-1-al and (Z)-6-nonenal being among the most abundant compounds in five seedless watermelon varieties (Beaulieu and Lea, 2006). Despite the fact that these compounds are often considered as oxidation products, they have also been reported to be responsible for the cucumber-like odor of watermelon fruit (Forss *et al.*, 1962; Fleming *et al.*, 1968; Yajima *et al.*, 1985; Schieberle *et al.*, 1990). According to Obando-Ulloa *et al.* (2010), the pleasant odor of cucumber has been attributed to (E,Z)-2,6-nonadien-1-al, whereas (E)-2-nonenal, 2-hexenal and three other saturated aldehydes contributed secondarily to overall flavour (Beaulieu and Grimm, 2001; Beaulieu and Baldwin, 2002; Palma-Harris *et al.*, 2002; Beaulieu, 2005). Moreover, Palma-Harris *et al.* (2002) reported that humans can detect differences in the intensity of cucumber flavour due to the presence of (E,Z)-2,6-nonadien-1-al and (E)-2-nonenal. However, even aldehydes that are not easily detectable or have a low human detection threshold could play an

important role in the flavour of various vegetables (Obando-Ulloa *et al.*, 2010). Therefore, from the results of the present study and for the specific scion-rootstock combinations, the presence of these compounds could have a negative effect on fruit volatiles profile and justify the effect of grafting.

The differences in the minerals concentrations could be associated with the effect of rootstock on water and nutrient uptake mainly due to the differences in the physical characteristics of the root system, such as vertical and lateral growth, whereas the rootstock-scion combination itself seems to be of major importance. In other studies, a similar effect of rootstock-scion combination on the K and Na concentration of plant tissues and fruit was reported (Colla *et al.*, 2006), as well as on the K and Mg concentration of fruit, when the combination of mini watermelon cv. 'Ingrid' and rootstock PS-313 was studied (Rouphael *et al.*, 2008; Proietti *et al.*, 2008), indicating that rootstock-scion combination may alter the potential of plants to exclude certain elements, such as K, Mg and Na. The mineral concentration of fruit was also affected, with K and Mg concentration being higher in grafted than ungrafted plants by 13 and 23.8%, respectively, whereas P and Ca concentrations were similar in both cases (Proietti *et al.*, 2008).

CONCLUSIONS

It is concluded that both the rootstock-scion combination and rootstock-scion compatibility are of major importance for fruit quality and total yield in watermelon cultivation. The contradictory reports regarding quality features of watermelon fruit could be attributed mainly to rootstock-scion compatibility, which affects scion vigor and water and mineral uptake and translocation and, consequently, the biosynthetic procedures. The effect of grafting on flavour and volatiles traits could

also be attributed to rootstock-scion compatibility; therefore, the choice of the scion and rootstock could be of major importance for the achievement of high yields and high quality fruit. However, further study is required to evaluate more scions and rootstocks so as to determine the effect of grafting technique on fruit quality and yield and propose specific combinations of scions and rootstocks according to market demands and soil deterioration and pathogens problems.

ACKNOWLEDGEMENTS

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اثر پیوند زدن روی طعم و بو(مواد فرار) ، کیفیت میوه ، و عملکرد هندوانه

س. ا. پتروپولوس، س. اولیمپیوس، ا. روپوکیس، گ. ولاچو، گ. انتاتسی، ا. پاراسکه وپولوس، و ه. س. پاسام

چکیده

هدف این پژوهش بررسی تاثیر پیوند زدن هیبرید های 'Obla F1'و 'Vanessa F1'هندوانه روی پایه148 Cucurbita maxima x Cucurbita moschata TZ و پایه 'Dias F1' گونه *Lagenaria* sp.بر طعم (مواد فرار)،عملکرد، ورشد گیاه بود. تجزیه موار فرار حاکی از حضور دو آلدئید به نام های (E)-2-nonenal و(E,Z)-2,6-nonadien-1-al) بود که ماده اخیر در گیاهان پیوندی غلظت بیشتری داشت. گیاهان پیوندی در مقایسه با غیرپیوندی ها رشد بیشتر، تولید بالاتر، و تعداد بیشتری میوه داشتند در حالیکه درصد ماده خشک برگ ها و ساقه های بوته های غیر پیوندی بیشتر بود. نتایج نشانی از تفاوت در میانگین وزن میوه، شکل میوه و ضخامت پوست رویه میوه نداشت. میوه های پیوندی دارای گوشت فشرده تری از غیرپیوندی ها بود ولی آب میوه آنها اسید کمتری داشت. طعم وبوی (ترکیبات فرار) میوه های پیوندی و غیرپیوندی با هم تفاوت داشت. ولی در مورد محتوی مواد قندی تفاوتی مشاهده نشد مگر در مورد هیبرید'Obla F1'. در این هیبرید ، غلظت سدیم ، کاراتینوید و لایکوپن در بافت های گیاهی و میوه و ویتامین ث میوه بوته های غیر پیوندی فقط در سال دوم بیشتر بود.نتیجه کلی این بود که ترکیب پایه وپیوندک در این پژوهش رشد گیاه، عملکرد و کیفیت میوه را تحت تاثیر قرار داد ونشان داد که انتخاب پایه و پیوندک اهمیت زیادی در دستیابی به بیشترین عملکرد و کیفیت محصول هندوانه دارد.