The Influence of Rootstock Selection on Fruit Quality Attributes of Watermelon

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Abstract: Grafting watermelon (*Citrullus lanatus*) to control Fusarium wilt has been practiced in Europe, the Middle East, and the Far East for decades. Until recently, grafting watermelon has not been practiced in the United States due to labor costs and land availability. There is some disagreement in the literature as to the effects that grafting has on watermelon fruit quality. This study was designed to determine the effects of grafted watermelon on fruit firmness, lycopene content, and total soluble solids (TSS) using five different rootstocks. When using *Cucurbita ficifolia* or *Cucurbita maxima* x *Cucurbita moschata* hybrid as the rootstock, watermelon fruit consistently had higher fruit firmness values. Other *C. maxima* x *C. moschata* hybrids or *Lagenaria siceraria* rootstocks generally produced lower or more varied fruit firmness values. Grafting increased fruit firmness by as much as 25% in some cases, but field and year effects were observed. In addition, grafting had no effect on lycopene content or TSS.

Furthermore, no off-flavors were detected in fruit from grafted plants, but there was a 5- to 7 day delay in fruit maturity compared to their non-grafted counterpart. Although environment can have a major influence on fruit quality attributes, rootstock selection may be equally important in achieving the desired outcome.

Keywords: *Citrullus lanatus*, *Cucurbita* spp., *Lagenaria* sp., grafting, lycopene, fruit firmness, total soluble solids.

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INTRODUCTION

As a result of the discontinuation of methyl bromide use for fumigation [1], the reduced availability of land for crop rotation, and the increased production of seedless fruit, watermelon (*Citrullus lanatus*) crops throughout the United States are highly susceptible to the increased incidence of soilborne diseases [2]. For example, approximately 75% of the watermelons grown in the United States are at risk for Fusarium wilt caused by *Fusarium oxysporum* f. sp. niveum [3]. Grafting watermelon onto other cucurbit rootstocks for the control of Fusarium wilt and environmental stresses has been practiced in Europe and Asia for many years [4-6]. In contrast, this cultural practice is a new concept for farmers in the United States because of the high costs associated with grafting [7]. For the reasons enumerated above, achieving a higher probability of producing a crop may soon outweigh the added cost of grafting. In addition to disease resistance, grafting may also provide benefits such as greater tolerance to salinity through improved nutrient and water absorption [8]. For the most part, grafting of watermelon onto other Cucurbitaceae rootstocks to provide soilborne disease resistance has been highly successful [6, 8]. With this success and with more discriminating consumers of watermelon fruit comes a second challenge: to produce a high quality fruit from grafted plants that is equal to or better than that of the non-grafted plant.

Watermelon fruit quality does not rely on a single property but depends, rather, upon a cadre of properties of which only a few have been identified and measured. Sugar content appears to be one of the more important quality indices routinely measured by scientists. However, as the marketing of watermelon fruit steadily evolves into its sale as fresh cut, crispness of the fruit and its storage stability become increasingly important. Sensory attributes are highly important, but they are difficult and expensive to objectively quantify. Finally, the ever-growing population of health-conscious consumers is demanding maximal nutritive value in their foods. As an important source of lycopene, watermelon's carotenoid content then becomes a worthy consideration. In attempts to address these fruit quality concerns, previous research has produced somewhat variable results. Grafting onto *Cucurbita* rootstocks has sometimes been associated with off-flavor development in the fruit [9]. Additionally, several authors have reported that grafting onto various rootstocks increased fruit yield but decreased soluble solids [10-12]. In contrast, other scientists found no difference in soluble solids between grafted and non-grafted [13, 14]. Some scion-rootstock combinations reportedly increased carotene [15] and fruit firmness [16]. Taken together, reports to date indicate that depending on the rootstock-scion selection, fruit

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yield and quality attributes may be either positively or negatively affected by grafting [4, 17-19].

Perhaps, the most impressive nutritional attribute of watermelon is lycopene. Red-fleshed watermelon is rich in lycopene, a member of the family of carotenoids that are some of the more important antioxidants in nature [20, 21]. There have been many published reports on the health benefits of diets high in lycopene for the prevention of certain types of cancer [22-25] as well as cardiovascular disease [26-28], although some of these claims have been called into question by the US Food and Drug Administration [29]. Regardless, as a result of the increased awareness of the potential virtues of lycopene in human health, consumer demand for lycopene-rich food and nutraceutical products is growing. In contrast to tomato lycopene [30], watermelon lycopene does not require thermal processing to increase its bioavailability in humans [31]. Depending on the cultivar and growing conditions, lycopene can vary from 34 to 112 µg/g fresh-weight [32]. Thus, red-fleshed watermelon is a rich source of readily bioavailable lycopene.

For the most part, previous studies on the effects of grafting were conducted during a single growing season and in a single field or plot. Thus, there has been no comprehensive investigation to evaluate the putative positive or negative effects of grafting on fruit quality as a part of year-to-year and field-to-field variability of growing conditions. The purpose of this study was to evaluate the effects of grafting different watermelon scions onto *Cucurbita ficifola*, *Lagenaria siceraria*, or *Cucurbita maxima* x *Cucurbita moschata* by quantifying grafting's effects on the resulting fruit quality attributes of flesh firmness and total soluble solids (TSS) as well as on the content of the phytonutrient, lycopene. Furthermore, these grafts were evaluated in separate fields over two growing seasons to gain insight into how fruit quality attributes were influenced by field and seasonal growing conditions.

MATERIALS AND METHODS

Plant Material

The experiment was conducted at two locations in 2004 and 2005 at the Lane Research Center at Lane, Oklahoma. Watermelon cvs. 'SS 7167,' 'SS 7177,' 'SS 7187,' 'SF 5244,' and 'SF 800' were used as the scion and were grafted onto one of the five rootstocks 'RS 1330,' 'RS 1332,' 'RS 1420,' 'RS 1421,' or 'RS 1422' (Table **1**). In addition to the cultivars listed above, four additional non-grafted watermelon cultivars were used in order to establish baseline data for the fruit quality indices tested. All grafted plants and their non-grafted counterparts were produced by Speedling Inc. of Alamo, TX, using the tongue-approach graft procedure [4]. In 2004, Field #1600 was planted 17 May and Field #5100 was planted 24 May. In 2005, Field #1400 was planted 27 May and Field #5100 was planted 1 June. The soil was classified as a Bernow sandy loam (fine-loamy, siliceous, thermic (Glossic Paleudalf). Field #1600 had 71% sand, 23% silt, and 3% clay. Field #5100 had 53% sand, 38% silt, and 9% clay. Field #1400 had 71% sand, 23% silt, and 6% clay. Plants were transplanted to the field on 1 m spacing within the row and 3 m between rows. Treatments consisted of three replications of 30 plants each arranged in a randomized complete block design. Irrigation was provided using drip-tape and plants were fertilized according to recommendations of Oklahoma State University using standard cultural practices.

Fruit Quality Analysis

Fruit were obtained from multiple harvests during the month of August in 2004 and 2005. Mature fruit were identified and numbered in the field and subsequently transported to the postharvest facility for further processing. For most treatment combinations, a minimum of 15 fruit were harvested and evaluated as described below. Each fruit was cut perpendicularly to the stem about one fourth of the distance

Table 1. Names, Properties and Source of Plant Material

Cultivar	Designation	Genus	Ploidy	Seed Source
Jamboree	Jamboree	*Citrullus lanatus*	Diploid	Rogers/Syngenta
Jubilee	Jubilee	*Citrullus lanatus*	Diploid	DeWitt Seed
Royal Sweet	Royal Sweet	*Citrullus lanatus*	Diploid	Seminis
Sangria	Sangria	*Citrullus lanatus*	Diploid	Rogers/Syngenta
Summer Flavor® Brand 800	SF 800	*Citrullus lanatus*	Diploid	Abbott & Cobb
Summer Sweet® Brand 5244	SS 5244	*Citrullus lanatus*	Triploid	Abbott & Cobb
Super Seedless® Brand 7167	SS 7167	*Citrullus lanatus*	Triploid	Abbott & Cobb
Super Seedless® Brand 7177	SS 7177	*Citrullus lanatus*	Triploid	Abbott & Cobb
Super Seedless® Brand 7187	SS 7187	*Citrullus lanatus*	Triploid	Abbott & Cobb
Root Stock 1330	RS 1330	*Cucurbita maxima* x *C. moschata*	Diploid	Abbott & Cobb
Root Stock 1332	RS 1332	*Lagenaria siceraria*	Diploid	Abbott & Cobb
Root Stock 1420	RS 1420	*Cucurbita ficifolia*	Diploid	Abbott & Cobb
Root Stock 1421	RS 1421	*Cucurbita maxima* x *C. moschata*	Diploid	Abbott & Cobb
Root Stock 1422	RS 1422	*Cucurbita maxima* x *C. moschata*	Diploid	Abbott & Cobb

from each end, and the two end sections discarded. Two additional perpendicular slices were made about 5 cm in thickness. Two cubes (5 cm/dimension) were used to determine fruit firmness using an 11.1 mm diameter head on a Wagner Force Dial FDK 10 (Wagner Instruments, Greenwich, CT) mounted onto a Clarke Metalworker BT1029 drill press (Clarke Metalworker, Perrysburg, OH). Two firmness readings were taken on each cube from opposite sides of the cube. Firmness was measured in lbs force and converted to Newtons (N). The same two cubes were used for determination of total soluble solids using an Atago PR-32 Digital Refractometer (Tokyo, JP). A 3 mm slice was removed from each cube for determination of total soluble solids (TSS). Two additional cubes were finely ground with a homogenizer (Brinkman Polytron Homogenizer, Westbury, NY) using a PTA-20TS generator for lycopene determination. Samples were assayed for lycopene either immediately after grinding or assayed following storage of the puree at –20ºC for less than a week. Lycopene contents of the purees were determined by the low volume hexane extraction method of Fish *et al*. [33].

Data Analysis

The initial analysis of variance (ANOVA) of the three fruit quality variables (firmness, lycopene, and total soluble solids) for each field and year included scion and rootstock as main effects and the interaction of scion by rootstock. Because of the significant interaction in 2004, it was decided to do ANOVAs of each rootstock within each field and year in order to compare scions on each rootstock. Likewise, ANOVAs were performed for each scion in each field and year in order to compare rootstocks with the same scion. Additionally, ANOVAs were performed for firmness and lycopene by field within year with a one sided test for increase of 5, 10, 15, 20 or 25 % as a result of grafting. A similar one-sided test was used to determine increases of 5, 10, 15, 20 or 25 % between diploid and triploid cultivars. For total soluble solids, the one-sided test was to detect decreases of 1, 2, 3, 4, or 5 % as a result of grafting. The same analysis was applied to compare diploid and triploid cultivars. Unless otherwise stated, least square means were calculated and presented, and the significance level used for comparisons was $p < 0.05$ with Tukey's adjustment when comparing more than three means.

RESULTS

Grafting and Fruit Quality: Rationale for Presentation of Results

During 2004 and 2005, four grafting experiments were established in three different field plots to determine the effects of grafting on the fruit quality indices of firmness, lycopene, and TSS. The cultivars 'Jamboree,' 'Royal Sweet,' 'Sangria,' and 'Jubilee' were included in the study to help establish baseline lycopene, TSS, and fruit firmness values for non-grafted commercial diploids. In 2004, there was a field effect, in which fruit were significantly ($p \leq 0.05$) firmer in Field #1600 than in Field #5100, in addition to a rootstock effect that was observed in both fields. However, in 2005, there was no field effect, but there were rootstock effects similar to those detected in 2004. Because there was a field effect on the fruit quality attributes tested for one of the crop years, the data are presented separately by field and by year.

Initially, the ANOVAs were applied separately for each year with all the data in each field, using a model that included scion, rootstock and the interaction of scion by rootstock. In 2004, the scion by rootstock interaction was significant for all responses in both fields, except for firmness in field #1600 where both scion and rootstock main effects were significant. In 2005, scion and rootstock significantly affected fruit firmness and TSS in both fields. For lycopene, the effect of scion was significant in both fields and the effect of rootstock was significant in field #1400. Scion by rootstock interaction was not significant in either field for any fruit quality attributes (Table **2**). For consistency of presentation of fruit quality attributes, Figs. (**1-6**) shall illustrate the least square means separately for each scion-rootstock combination even though the interaction was not significant in 2005. The error bars in the figures represent the pooled standard error, which is appropriate for the data from the entire experiment.

Since analyses were conducted by scion groups or the diploids only, which represented a subset of the data, the least square means and the pooled standard errors may be

Table 2. Probability of a Greater F from Analyses of Variance Done Separately for Each Field in Each Year

	Year	2004		2005	
Response	Effect	Field 1600	Field 5100	Field 1400	Field 5100
Firmness (N)	Scion	<0.0001	<0.0001	<0.0001	<0.0001
	Root stock	<0.0001	<0.0001	<0.0001	<0.0001
	Scion X root stock	0.4928	0.0020	0.8141	0.9479
Lycopene (μg/g)	Scion	<0.0001	<0.0001	<0.0001	<0.0001
	Root stock	0.4573	<0.0001	0.0126	0.1654
	Scion X root stock	0.0002	0.0008	0.1151	0.2516
Sugar (%)	Scion	0.0183	<0.0001	<0.0001	<0.0001
	Root stock	0.6644	<0.0001	0.0005	0.0058
	Scion X root stock	0.0081	0.0004	0.2789	0.0628

Shaded cells indicate significance at $p \leq 0.05$.

Table 3. Comparison of Fruit Quality Attributes of Diploid Versus Triploid Watermelon Cultivars

FIRMNESS (N)					p-Value for Difference	p-Value for One-Sided Test of Increase of at Least				
Year	Field	Ploidy	LS Mean	Difference		5%	10%	15%	20%	25%
2004	1600	diploid	7.6							
		triploid	12.8	5.2	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	5100	diploid	7.4							
		triploid	9.6	2.2	<0.0001	0.0005	0.0062	0.0445		
2005	1400	diploid	8.3							
		triploid	10.4	2.1	0.0001	0.0015	0.0130	0.0835		
	5100	diploid	7.9							
		triploid	10.4	2.5	<0.0001	<0.0001	0.0009	0.0091	0.0635	

LYCOPENE (µg/g)					p-Value for Difference	p-Value for One-Sided Test of Increase of at Least				
Year	Field	Ploidy	LS Mean	Difference		5%	10%	15%	20%	25%
2004	1600	diploid	52.4							
		triploid	55.2	2.8	0.1641					
	5100	diploid	57.3							
		triploid	62.4	5.2	0.0045	0.2143				
2005	1400	diploid	49.7							
		triploid	52.7	3.0	0.1023					
	5100	diploid	65.6							
		triploid	70.7	5.1	0.0347	0.4493				

SOLUBLE SOLIDS (%)					p-Value for Difference	p-Value for One-Sided Test of Decrease of at Least				
Year	Field	Ploidy	LS Mean	Difference		1%	2%	3%	4%	5%
2004	1600	diploid	10.2							
		triploid	9.9	-0.3	0.1050					
	5100	diploid	10.7							
		triploid	11.3	0.6	<0.0001	*				
2005	1400	diploid	11.6							
		triploid	11.5	-0.2	0.3533					
	5100	diploid	11.9							
		triploid	12.2	0.3	0.0612					

*Test was for decrease. This change was an increase.
Shaded block indicates statistical significance at $p \leq 0.05$ level.

different because the data set is a smaller subset of the whole. These analyses of subsets were applied because of the significant scion by rootstock interaction observed in 2004. The same subset analysis was used for 2005 even though the interaction was not significant in that year.

In all fields in both years, firmness was significantly different between diploid and triploid cultivars (Table **3**). Firmness of triploid fruit was 10% to 25% higher than for diploid fruit. Lycopene was significantly different in field #5100, but was less than 5% greater and was not different in fields #1600 and #1400. With respect to TSS, the differences were less than 1% or not significant between diploids and triploids.

Since a statistically significant crop-year effect was observed for the fruit quality parameters that were measured, it was deemed important to present daily maximum tempera-

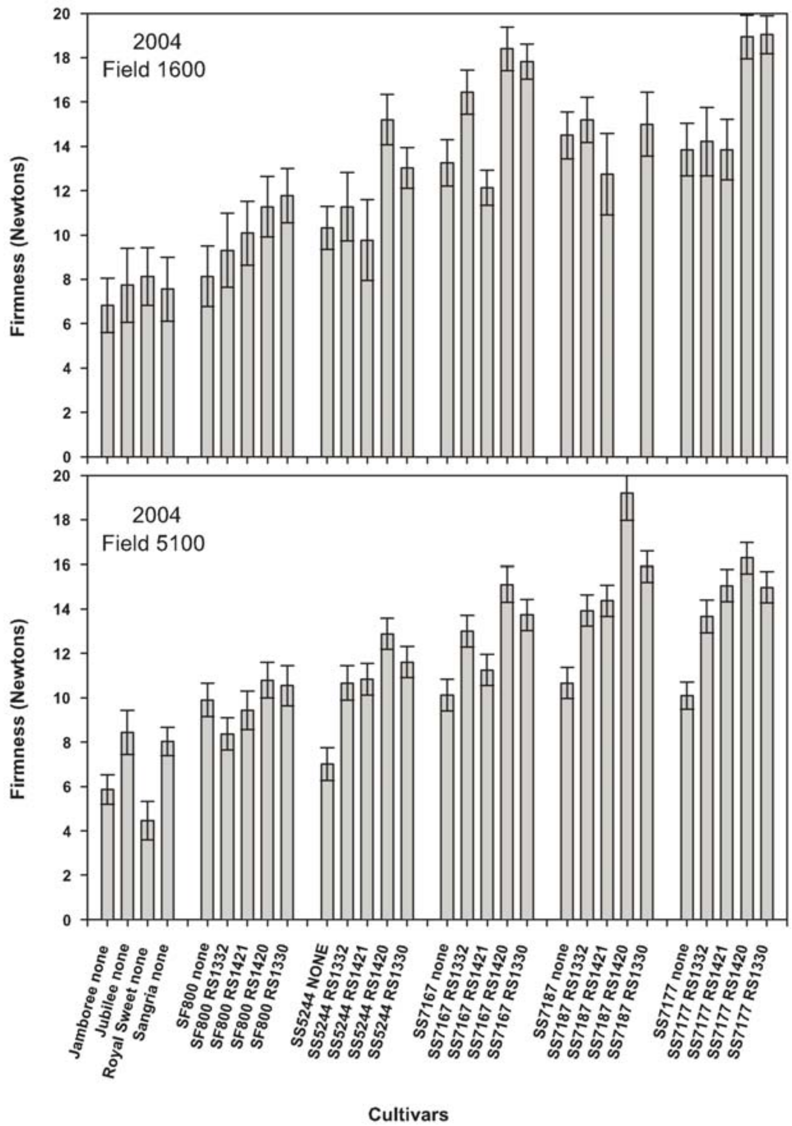


Fig. (1). Fruit firmness measurements from grafted and non-grafted watermelon plants in 2004. Method of measurement is described in Materials and Methods. Bars represent pooled standard errors at $p \leq 0.05$.

ture, cumulative daily sunlight, and rainfall at the Lane, OK Research Station for the 2004 and 2005 growing seasons. These Mesonet data are presented on a day-to-day basis in Appendix Fig. (**1**). Appendix Table **1** summarizes these data as mean maximum temperature, average daily sunlight, and total rainfall amount in 30 day blocks from the date of planting for each field and each year. Maximum temperatures averaged about 3º C cooler during the 2004 growing season than during the 2005 growing season. The average solar radiation for the first 60 days in 2004 was about 3.7 MJ/m^2 less than in 2005. Additionally, there was about 36% greater rainfall during the 2004 growing season (32.4 cm) than during the 2005 growing season (20.7 cm). Although there were widely different temperatures and rainfall frequency and amounts during the cropping season of 2004 and 2005, no attempt was made to ascribe fruit responses as a function of single or combined environmental factors. In each year of the study, supplemental irrigation was applied when needed. Visual and tactile observations of soil and plant moisture were used to determine the need for and timing of such irrigation. When needed, irrigation was applied through drip irrigation systems for 2-4 hours, or until the area of soil in and along the plant row was near saturation.

Year 2004

Fruit Firmness

The firmness responses to grafting by watermelon produced in two separate fields in 2004 are presented in Fig. (**1**), Table **4**, and Appendix Tables **2** and **4**. In field #1600, firmness of fruit from non-grafted plants ranged from 14.5 to 6.8 N as compared to 19.0 to 9.3 N in fruit from grafted plants (Fig. **1**, Appendix Tables **2** and **4**). Fruit firmness among non-grafted diploids did not differ significantly from each other with an overall average of 7.0 N. Although the non-grafted diploid ‘SF800’ had a similar least square mean (8.1 N) to the other non-grafted diploids, when grafted onto rootstock ‘RS 1330’ the resulting fruit had a firmness of 11.8 N. Fruit from all grafted triploids generally exhibited an increase in fruit firmness as compared to their non-grafted

Table 4. Comparison and Percentage Change in Fruit Firmness (N) from Grafted and Non-Grafted Watermelon Plants Grown in Two Fields Over Two Years at Lane, OK

						p-Value for Difference	p-Value for One-Sided Test of Increase of at Least				
Year	**Field**	**Cultivar**	**Grafted**	**LS Mean**	**Difference**		**5%**	**10%**	**15%**	**20%**	**25%**
2004	1600		No	12.2							
			Yes	14.9	2.7	<0.0001	0.0019	0.0269			
	5100		No	9.6							
			Yes	13.0	3.4	<0.0001	<0.0001	<0.0001	<0.0001	0.0018	0.0392
2004	1600	SF800	No	8.1							
			Yes	10.8	2.7	0.0115	0.0326				
		SS5244	No	10.3							
			Yes	13.0	2.7	0.0058	0.0264				
		SS7167	No	13.3							
			Yes	15.9	2.7	0.0928					
		SS7177	No	13.9							
			Yes	17.6	3.7	0.0165	0.0503				
		SS7187	No	14.5							
			Yes	14.7	0.2	0.8575					
2004	5100	SF800	No	9.9							
			Yes	9.7	-0.2	0.7974					
		SS5244	No	7.0							
			Yes	11.5	4.5	<0.0001	<0.0001	<0.0001	0.0003	0.0011	0.0037
		SS7167	No	10.1							
			Yes	13.2	3.0	0.0003	0.0024	0.0148			
		SS7177	No	10.1							
			Yes	15.0	4.9	<0.0001	<0.0001	<0.0001	<0.0001	0.0007	0.0052
		SS7187	No	10.7							
			Yes	15.2	4.5	<0.0001	<0.0001	0.0002	0.0016	0.0094	0.0430
2005	1400		No	10.1							
			Yes	11.7	1.6	0.0111	0.0782				
	5100		No	10.2							
			Yes	11.8	1.5	0.0124	0.0934				
2005	1400	SF800	No	8.8							
			Yes	9.7	0.9	0.3888					
		SS5244	No	8.9							
			Yes	10.3	1.5	0.3299					
		SS7167	No	9.7							
			Yes	12.0	2.3	0.0189	0.0538				
		SS7177	No	12.1							
			Yes	13.3	1.2	0.3164					
		SS7187	No	10.9							
			Yes	12.8	1.9	0.0960					
2005	5100	SF800	No	9.4							
			Yes	10.6	1.2	0.2994					
		SS5244	No	8.7							
			Yes	10.2	1.6	0.2432					
		SS7167	No	10.8							
			Yes	12.4	1.6	0.2346					
		SS7177	No	10.9							
			Yes	12.6	1.8	0.1068					
		SS7187	No	11.4							
			Yes	12.9	1.5	0.2547					

Shaded block indicates statistical significance at $p \leq 0.05$ level.

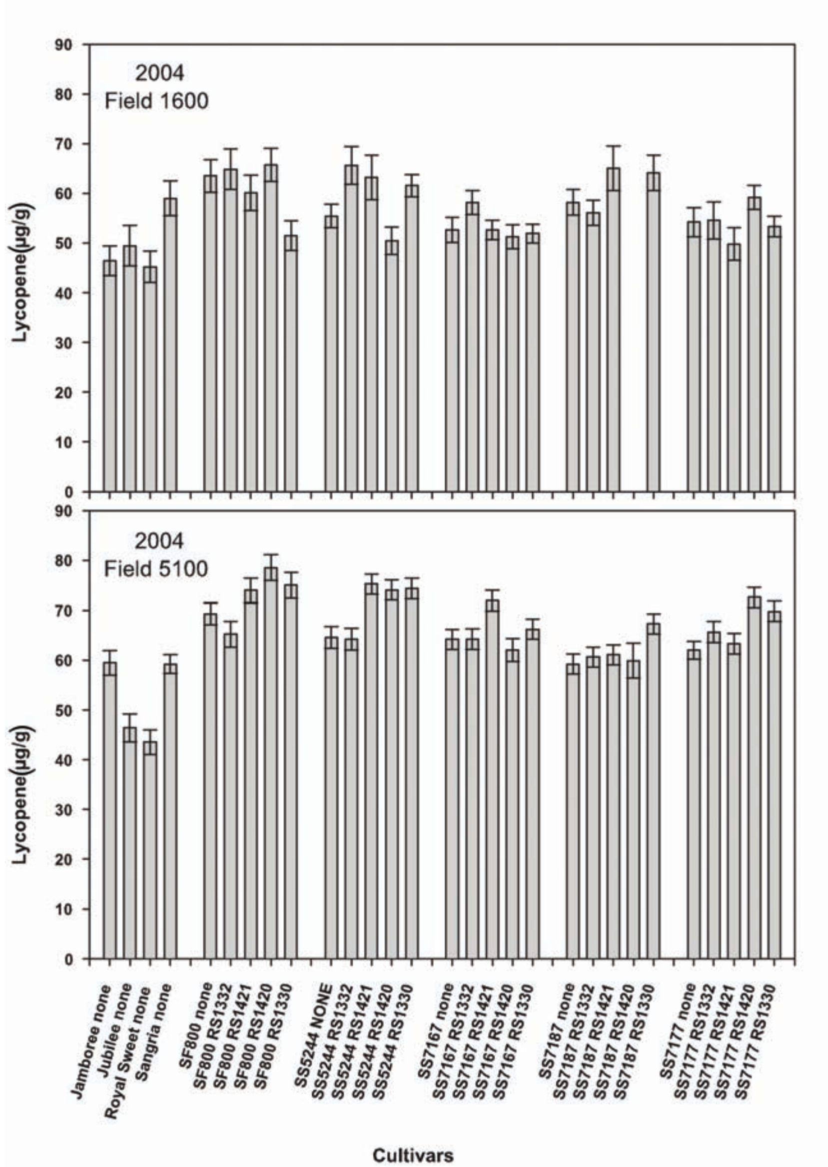


Fig. (2). Lycopene content (µg/g tissue) in watermelon fruit from grafted and non-grafted plants in 2004. Method of measurement is described in Materials and Methods. Bars represent pooled standard errors at p≤ 0.05.

counterpart. The two rootstocks that consistently produced higher fruit firmness values were 'RS 1330' (*C. maxima* x *C. moschata*) or 'RS 1420' (*C. ficifolia*) except when 'SS7187' was the scion (Fig. **1**). Over all scions, there was a significant grafting effect that resulted in increasing fruit firmness by 5% (Table **4**).

In field #5100, firmness ranged from 10.7 to 4.5 N for fruit from non-grafted plants while the range for fruit firmness from grafted plants was 19.2 to 8.4 N (Fig. **1**, Appendix Tables **2** and **4**). Although the non-grafted diploids, 'Jubilee' and 'Sangria,' exhibited similar fruit firmness values as in field #1600, 'Jamboree' and 'Royal Sweet' fruit were significantly different when compared to 'Jubilee' and 'Sangria.' For the diploid SF800 there was no significant difference in firmness of fruit with respect to grafted or non-grafted plants. Fruit of grafted-triploid plants consistently exhibited significantly higher firmness values than their non-grafted counterparts. As a rule, fruit from scions grafted onto rootstocks 'RS 1330' or 'RS 1420' produced fruit with higher fruit firmness values when compared to fruit from scions grafted onto rootstocks 'RS 1332' (*L. siceraria*) or 'RS 1421' (*C. maxima* X *C. moschata*). Considering all scions together in field #5100, there was a significant grafting effect that resulted in increasing fruit firmness by 20% (Table **4**). There was no grafting effect for 'SF800.' However, grafting produced a 25% increase in fruit firmness in cultivars 'SS5244' and 'SS7177,' a 20% increase in 'SS7187,' and a 10% increase in 'SS7167' (Table **4**).

Lycopene

The lycopene contents of grafted and control watermelons produced in fields 1600 and 5100 during 2004 are summarized in Fig. (**2**), Table **5**, and Appendix Tables **2** and **4**. In field #1600, lycopene content for 'Sangria' was significantly ($p \leq 0.05$) greater than for 'Jamboree' or 'Royal Sweet' ranging from 58.0 to 45.2 µg/g of tissue (Fig. **2**). There were

Table 5. Comparison of Fruit Lycopene (µg/g) from Grafted and Non-Grafted Watermelon Plants Grown in Two Fields Over Two Years at Lane, OK

						p-Value for Difference	p-Value for One-Sided Test of Increase of at Least				
Year	Field	Cultivar	Grafted	LS Mean	Difference		5%	10%	15%	20%	25%
2004	1600		No	56.3							
			Yes	56.2	0.0	0.9835					
	5100		No	63.6							
			Yes	68.3	4.7	<0.0001	0.1964				
2004	1600	SF800	No	63.5							
			Yes	59.6	-3.9	0.3074					
		SS5244	No	55.4							
			Yes	59.2	3.7	0.2107					
		SS7167	No	52.7							
			Yes	53.2	0.6	0.8564					
		SS7177	No	54.2							
			Yes	54.7	0.5	0.8822					
		SS7187	No	58.2							
			Yes	59.9	1.7	0.6249					
2004	5100	SF800	No	69.3							
			Yes	73.2	3.9	0.1730					
		SS5244	No	64.6							
			Yes	72.3	7.7	0.0023	0.0741				
		SS7167	No	64.2							
			Yes	66.3	2.1	0.3965					
		SS7177	No	62.0							
			Yes	68.0	5.9	0.0037	0.1616				
		SS7187	No	59.3							
			Yes	62.7	3.5	0.1930					
2005	1400		No	52.1							
			Yes	55.2	3.1	0.0847					
	5100		No	71.5							
			Yes	70.9	-0.6	0.7212					
2005	1400	SF800	No	49.8							
			Yes	58.1	8.2	0.0730					
		SS5244	No	56.6							
			Yes	60.3	3.7	0.2811					
		SS7167	No	49.6							
			Yes	49.0	-0.6	0.8246					
		SS7177	No	50.4							
			Yes	53.1	2.7	0.3018					
		SS7187	No	54.2							
			Yes	55.7	1.5	0.6715					
2005	5100	SF800	No	74.6							
			Yes	75.1	0.4	0.8982					
		SS5244	No	76.1							
			Yes	74.8	-1.4	0.6339					
		SS7167	No	66.5							
			Yes	67.4	0.9	0.8219					
		SS7177	No	68.3							
			Yes	67.9	-0.4	0.9292					
		SS7187	No	71.9							
			Yes	69.2	-2.7	0.2672					

Shaded block indicates statistical significance at $p \leq 0.05$ level.

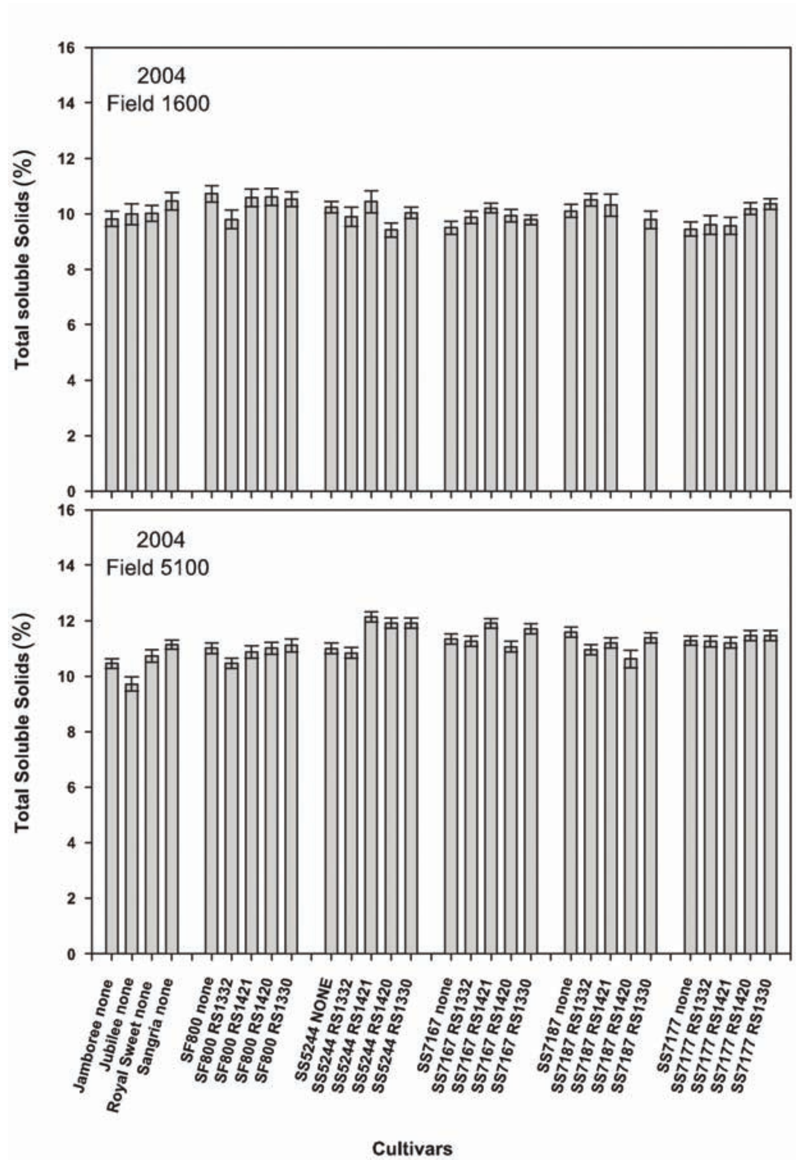


Fig. (3). Total soluble solids in watermelon fruit from grafted and non-grafted plants in 2004. Method of measurement is described in Materials and Methods. Bars represent pooled standard errors at $p \leq 0.05$.

no differences within cultivars used as scions 'SS7167,' 'SS7177,' or 'SS7187' due to grafting (Fig. **2**, Table **5**) and a minimal grafting effect on lycopene when evaluating all scions (Appendix Tables **2** and **4**).

In field #5100, lycopene content ranged from 75.5 to 43.6 µg/g of tissue, which was generally higher than lycopene values observed in field #1600. There were no differences in lycopene content between grafted and non-grafted 'SS7187.' Scions 'SF800,' 'SF5244,' 'SS7167' and 'SS7177' exhibited a scion by rootstock interaction cited earlier (Fig. **2**, Appendix Table **2**). Although significant differences were occasionally observed, there was never a change in lycopene content by as much as 5% in either field (Table **5**).

Total Soluble Solids

Total soluble solids for watermelons from the 2004 harvest of fields 1600 and 5100 are presented in Fig. (**3**), Table **6**, and Appendix Tables **2** and **4**. In field #1600, TSS ranged between 10.7 and 9.4%. For all scions except 'SF5244,' there were no significant effects due to grafting (Fig. **3**, Appendix Tables **2** and **4**). In field #5100, TSS ranged between 12.1 and 9.7% (Fig. **3**, Appendix Tables **2** and **4**). 'Sangria' (11.1) had significantly ($p \leq 0.05$) more TSS as compared to the other non-grafted diploids. There was no difference in TSS content within the grafted or non-grafted 'SF800,' 'SS7177,' or 'SS7187.' Though there were statistically significant differences in TSS for scions 'SF800' and 'SF5244,' these differences probably were not relevant but due to the very low standard errors found in the TSS data for both fields. Regardless of grafting, there was never as much as a 1% decrease in TSS in either field (Table **6**).

Year 2005

Fruit Firmness

In crop year 2005, the fruit firmness of non-grafted plants from field 1400 ranged from 12.0 to 7.5 N while the range of fruit firmness of grafted plants from the same field was 15.4

Table 6. Comparison of Fruit Total Soluble Solids (%) from Grafted and Non-Grafted Watermelon Plants Grown in Two Fields Over Two Years at Lane, OK

						p-Value for Difference	p-Value for One-Sided Test of Decrease of at Least				
Year	**Field**	**Cultivar**	**Grafted**	**LS Mean**	**Difference**		**1%**	**2%**	**3%**	**4%**	**5%**
2004	1600		No	10.0							
			Yes	10.1	0.1	0.4618					
	5100		No	11.3							
			Yes	11.3	0.1	0.4050					
2004	1600	SF800	No	10.7							
			Yes	10.4	-0.3	0.3836					
		SS5244	No	10.2							
			Yes	9.9	-0.4	0.1171					
		SS7167	No	9.5							
			Yes	10.0	0.5	0.0802					
		SS7177	No	9.5							
			Yes	10.1	0.6	0.0749					
		SS7187	No	10.1							
			Yes	10.3	0.2	0.5321					
2004	5100	SF800	No	11.0							
			Yes	10.8	-0.2	0.4539					
		SS5244	No	11.0							
			Yes	11.7	0.7	0.0088	*				
		SS7167	No	11.3							
			Yes	11.5	0.2	0.4469					
		SS7177	No	11.3							
			Yes	11.4	0.1	0.5841					
		SS7187	No	11.6							
			Yes	11.1	-0.5	0.0415	0.1240				
2005	1400		No	11.5							
			Yes	11.1	-0.4	0.0122	0.0674				
	5100		No	12.1							
			Yes	11.7	-0.4	0.0214	0.1107				
2005	1400	SF800	No	11.8							
			Yes	11.7	0.0	0.9420					
		SS5244	No	11.7							
			Yes	11.4	-0.3	0.3329					
		SS7167	No	11.3							
			Yes	11.1	-0.2	0.2273					
		SS7177	No	11.3							
			Yes	10.6	-0.7	0.0520					
		SS7187	No	11.5							
			Yes	10.8	-0.7	0.0124	0.0312				
2005	5100	SF800	No	11.9							
			Yes	11.8	-0.1	0.6905					
		SS5244	No	12.7							
			Yes	12.1	-0.6	0.0202	0.0556				
		SS7167	No	12.4							
			Yes	12.2	-0.2	0.4563					
		SS7177	No	11.6							
			Yes	11.3	-0.3	0.2282					
		SS7187	No	11.9							
			Yes	11.2	-0.7	0.0457	0.0905				

*Test was for decrease. This change was an increase.
Shaded block indicates statistical significance at $p \leq 0.05$ level.

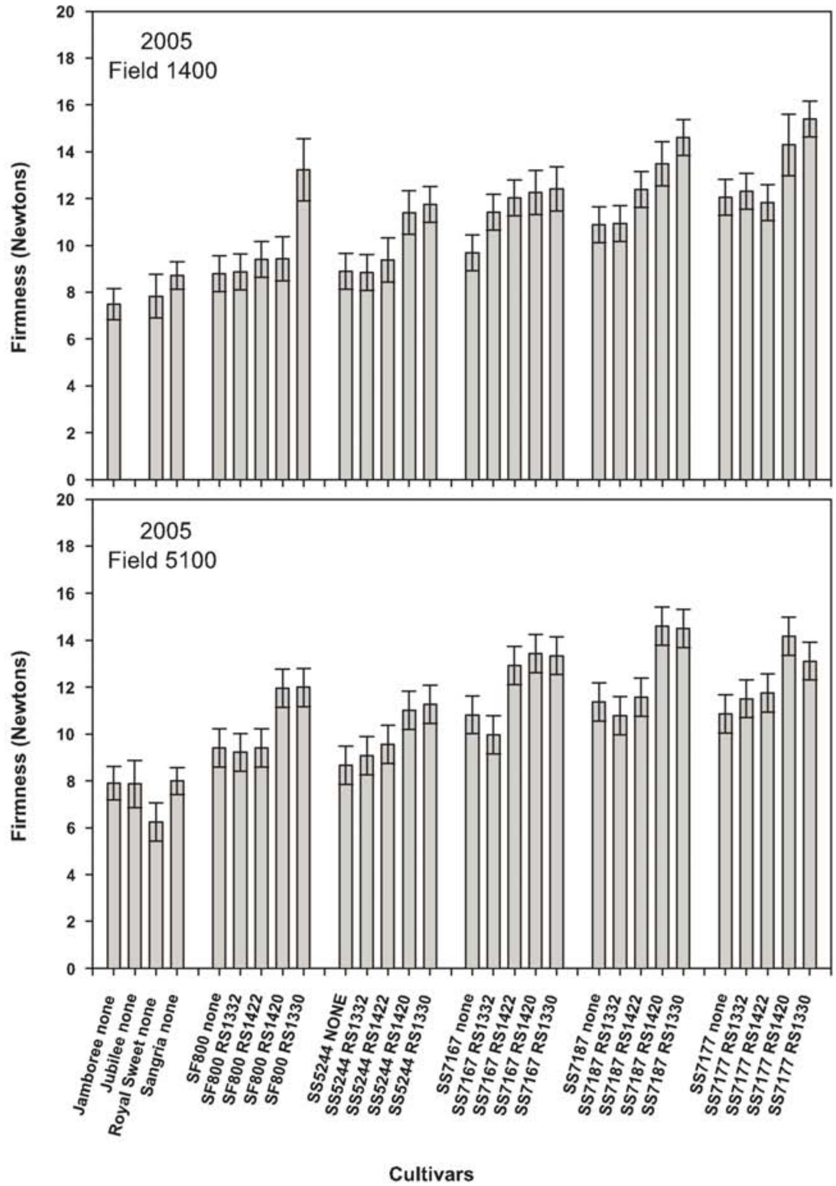


Fig. (4). Fruit firmness measurements from grafted and non-grafted watermelon plants in 2005. Method of measurement is described in Materials and Methods. Bars represent pooled standard errors at $p \leq 0.05$.

to 8.8 N (Fig. **4**, Appendix Tables **3** and **5**). Rootstocks 'RS 1330' (*C. maxima* x *C. moschata*) and 'RS 1420' (*C. ficifolia*) produced fruit with the highest firmness values (Appendix Table **5**). There were no differences in fruit firmness between grafted and non-grafted fruit in 'SF5244' and 'SS7167' (Appendix Table **3**).

In field #5100 for crop year 2005, fruit firmness from non-grafted plants ranged from 11.4 to 6.2 N while the range of fruit firmness from grafted plants was 14.6 to 9.1 N (Fig. **4**, Appendix Tables **3** and **5**). Scions 'SF800,' 'SF5244,' 'SS7167,' 'SS7177' showed no significant differences between non-grafted and grafted rootstocks for fruit firmness (Appendix Table **3**). With scion 'SS7187,' rootstocks 'RS 1330' and 'RS 1420' produced significantly greater fruit firmness than other rootstocks and non-grafted fruit. In both fields, there was a significant increase in fruit firmness due to grafting, although less than 5% (Table **4**).

Lycopene

In field #1400 for crop year 2005, fruit from non-grafted plants ranged from 56.6 to 45.2 µg/g of tissue, whereas, fruit from grafted plants ranged from 69.1 to 47.1 µg/g of tissue (Fig. **5**, Appendix Tables **3** and **5**). Only in fruit of the non-grafted diploids was there a significant difference in lycopene content, where 'Sangria' (53.2 µg/g) had more lycopene than either 'Jamboree' (47.5 µg/g) or 'Royal Sweet' (45.2 µg/g) (Appendix Table **3**).

In field #5100, fruit from non-grafted plants ranged from 76.1 to 58.5 µg/g of tissue, whereas, fruit from grafted plants ranged from 78.9 to 61.3 µg/g of tissue (Fig. **5**, Appendix Tables **3** and **5**). There were no significant differences in lycopene content among fruit of grafted plants or fruit from the non-grafted diploids, except for scion 'SF5244' when grafted onto 'RS 1330' or 'RS 1420' where it produced

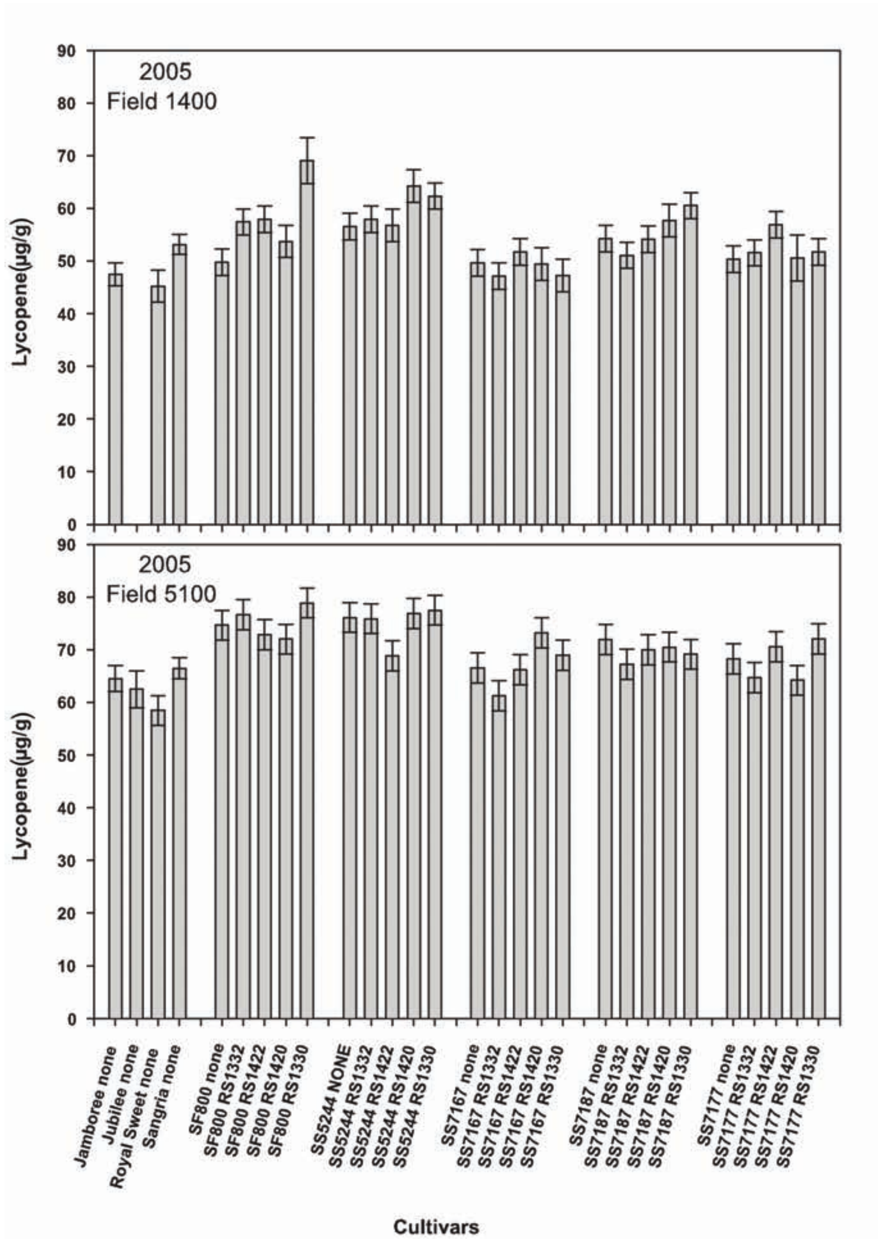


Fig. (5). Lycopene content (μg/g tissue) in watermelon fruit from grafted and non-grafted plants in 2005. Method of measurement is described in Materials and Methods. Bars represent pooled standard errors at p≤ 0.05.

higher lycopene. In no case, did grafting to these rootstocks decrease lycopene. Further, there was never a change in lycopene content by as much as 5% in either field (Table **5**).

Total Soluble Solids

In field #1400 during crop year 2005, TSS in fruit of non-grafted plants ranged from 11.4 to 11.3%, whereas, fruit of grafted plants ranged from 12.0 to 9.9% (Fig. **6**, Appendix Tables **3** and **5**). Even where there were statistically significant differences in TSS these differences were less than 2% (Table **6**).

In field #5100 for crop year 2005, TSS in fruit from non-grafted plants ranged from 12.74 to 11.2%, whereas, fruit of grafted plants ranged from 12.6 to 10.9% (Fig. **6**, Appendix Tables **3** and **5**). Similar to the situation in field #1400, there was never as much as a 2% change in TSS in field #5100 (Table **6**).

DISCUSSION

This study demonstrates that the only fruit quality trait consistently affected by grafting watermelon scion onto various rootstocks was fruit firmness. However, fruit firmness was also strongly influenced by year-to-year interactions with field and climatic conditions. As a rule, fruit of scions grafted onto ‘RS 1330’ (*C. maxima* x *C. moschata*) or ‘RS 1420’ (*C. ficifolia*) exhibited higher fruit firmness values when compared to the other *C. maxima* x *C. moschata* hybrids or *L. siceraria* rootstocks used in this study. Although grafting increased fruit firmness by as much as 25% in some cases, we also observed field and year effects. Liu *et al*. [15] reported no difference in fruit ‘texture’ (firmness?) when diploid watermelons were grafted onto five different rootstocks consisting of *L. siceraria* or *C. ficifolia*. However, Yamasaki *et al*. [34] reported a significant increase in fruit

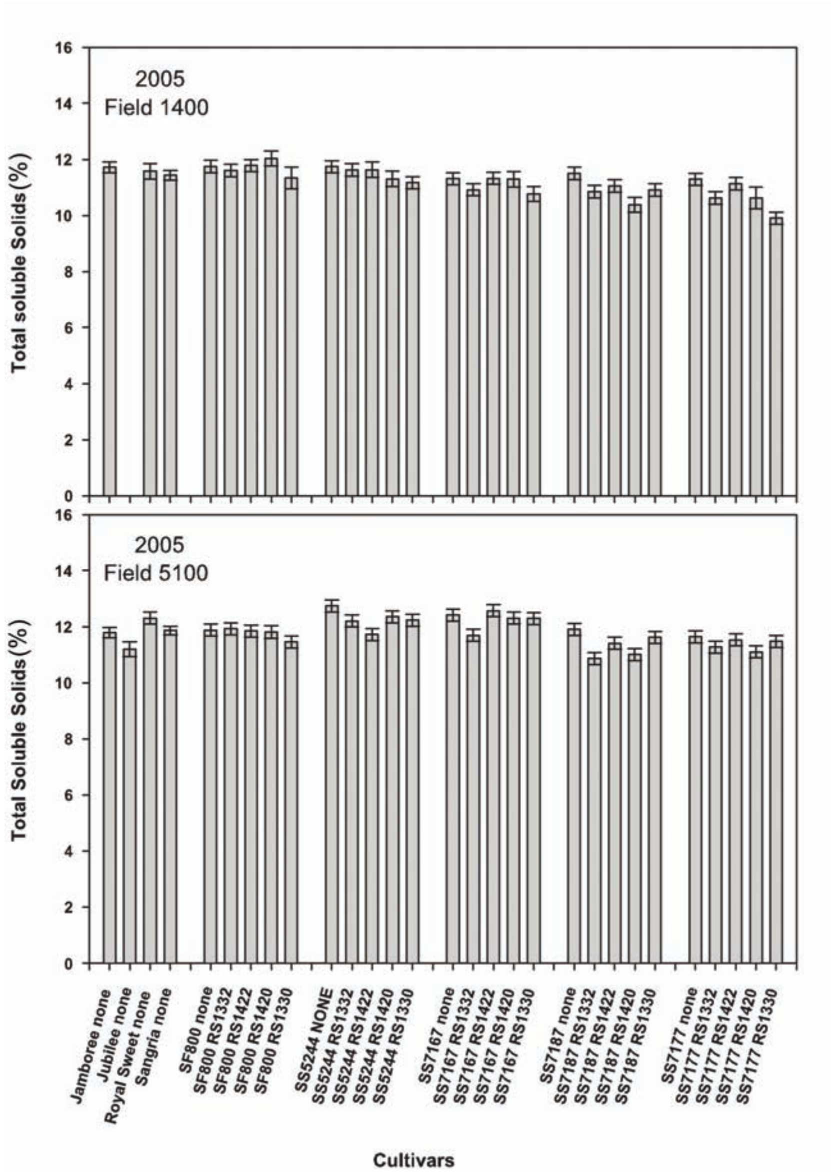


Fig. (6). Total soluble solids in watermelon fruit from grafted and non-grafted plants in 2004. Method of measurement is described in Materials and Methods. Bars represent pooled standard errors at p≤ 0.05.

firmness when watermelon scion was grafted onto *C. maxima* x *C. moschata* (3.17 N) but not when grafted onto *L. siceraria* (2.79 N). Yetisir *et al*. [16] measured a significant increase in fruit firmness when 'Crimson Tide' watermelon (diploid) was grafted onto *C. moschata* (12.63 N) or *C. maxima* (11.62 N) as compared to the non-grafted control (6.85 N). In contrast, he found no increase in fruit firmness when 'Crimson Tide' was grafted onto various *L. siceraria* or *Cucurbita* sp. hybrids. The present study clearly demonstrates that the non-grafted triploid watermelons ('SS7167,' 'SS7177,' and 'SS7187') were inherently firmer (10-25%) than the diploids ('Jamboree,' 'Jubilee,' 'Royal Sweet,' 'Sangria,' and 'SF800').

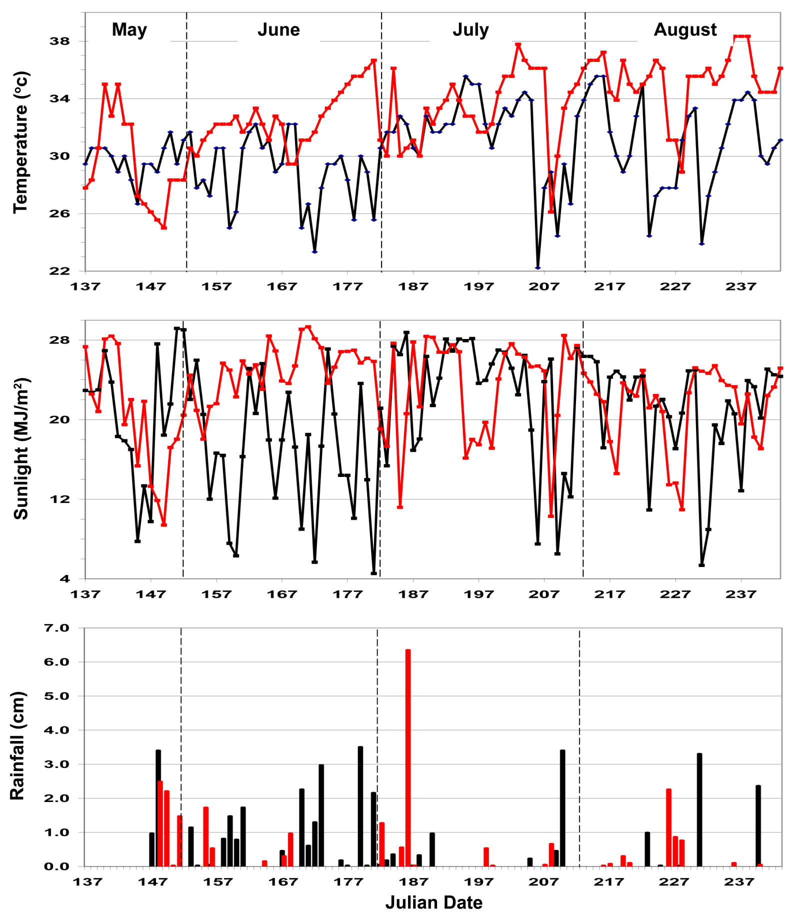
From a nutraceutical standpoint, lycopene may be the most important component of watermelon fruit. In the present study, lycopene ranged between 43.6 to 78.5 µg/g of tissue. These values are consistent with those reported by Perkins-Veazie *et al*. [32], in which watermelon cultivars can have a wide range of values for lycopene content ranging from a low of <50 µg/g to a very high >90 µg/g of tissue. Although grafting did produce a statistically significant increase in lycopene content in a few cases, the increase was always less than 5%. Contrary to our results, Proietti *et al*. [35] noted a 40% increase in lycopene content in a mini-watermelon grafted onto a C. *moschata* x *C. maxima* rootstock. Liu *et al*. [15] grafted seeded watermelon onto five different rootstocks of *L. siceraria* or *C. ficifolia* and noted higher amino acid and carotene content in fruit of grafted vs. non-grafted watermelon. As noted in fruit firmness, lycopene content of watermelon exhibited both field and year effects in this study and demonstrates that environment may provoke a greater influence on lycopene than grafting.

Sugar content appears to be one of the most important characteristics of a good-quality watermelon, based on the fruit quality indices routinely measured by scientists. Previous research has generally shown that grafting has little or no effect on TSS content in watermelon fruit [13, 36]. Miguel *et al*. [14] noted no significant effect on TSS of fruit when grafting watermelon onto *C. moschata*, *C. maxima* x *C. moschata*, or *L. siceraria* rootstocks under field conditions. However, grafting the same watermelon onto *C. maxima* x *C. moschata* under greenhouse conditions decreased TSS in the fruit suggesting a possible interaction with environment on fruit quality [12]. Yetisir and Sari [19] also noted that there is a rootstock effect on TSS in the fruit. Although some researchers [10, 16, 34, 37] have reported a significant reduction in TSS in fruit of grafted watermelon, the decrease is rather small and the TSS levels are generally above 10%, which is the value required to achieve #1 grade by the United States Standards for Grades of Watermelons [38]. Liu *et al*. [15] reported no difference in taste or fruit maturity when grafting watermelon onto *L. siceraria* or *C. ficifolia*. Yamasaki *et al*. [34] noted inferior fruit flavor when watermelon was grafted onto *C. maxima* x *C. moschata* but not *L. siceraria*. Although no taste panel was used in the present study, anecdotal responses by consumer tasting rated the fruit flavor of grafted watermelon equal to or superior to non-grafted watermelon (data not presented). We did observe that fruit maturity of grafted watermelon was delayed about 5 to 7 days beyond the non-grafterd counterpart which could account for reduced TSS and off flavor as noted in some grafting studies. Mondal *et al*. [39] also noted late maturation of watermelon fruit using *L. leucantha*, *C. moschata*, and *C. maxima* x *C. moschata* as the rootstock. The observed delay in fruit maturity may be explained by Salam *et al*. [40] who recorded a 4-day delay in the appearance of first female flowers when watermelon was grafted onto *L. siceraria*.

Historically, the selection of rootstocks has been toward resistance to disease and/or environmental stresses [5, 8]. *L. siceraria* has been frequently used as a rootstock for watermelon, but the incidence of Fusarium wilt caused by *F. oxysporum* f. sp. *lagenariae* has dramatically increased in major watermelon production regions in Japan and Korea [5, 41]. As a result, there has been an effort to find other rootstocks that are resistant to Fusarium wilt. Each of the rootstocks used in this study were highly resistant/tolerant to race 2 of *F. oxysporum* f. sp. *niveum* and *Verticillium dahliae* as determined by greenhouse inoculation of the rootstocks alone (unpublished data). Although some studies have concluded that *Cucurbita* sp. rootstocks may produce inferior watermelon fruit quality [5, 42], our studies do not support that conclusion.

CONCLUSION

To our knowledge, this study represents the most comprehensive evaluation carried out to date on the effects of grafted watermelon with respect to fruit firmness and lycopene content. Although environment can have a major influence on fruit quality attributes, rootstock selection appears to be equally important to achieving the desired outcome.



Appendix Fig. (1). Environmental parameters (temperature, sunlight, and rainfall) measured during the watermelon growing seasons 2004 (black) and 2005 (red).

Appendix Table 1. Environmental Data for Different Fields in 2004 and 2005

Crop Year	Field #	Planting Date	Time Interval	Max Temp (°C)	Min Temp (°C)	Mean Solar Radiation	Rainfall
			(da)	(Mean)	(Mean)	MJ/m^2	(cm)
2004	1600	17-May	0-30	29.6	19.5	19.2	10.4
			30-60	30.3	20.8	20.1	15.4
			60-90	30.9	18.6	21.8	5.1
2004	5100	24-May	0-30	29.1	19.7	17.6	18.0
			30-60	31.4	20.5	22.3	7.8
			60-90	30.0	18.3	20.0	8.4
2005	1400	27-May	0-30	30.9	19.1	22.9	9.9
			30-60	33.8	21.2	23.7	8.8
			60-90	34.6	21.1	21.8	5.2
2005	5100	1-June	0-30	32.4	19.7	24.9	3.7
			30-60	33.1	20.9	23.0	9.5
			60-90	35.3	21.7	21.4	4.5

Appendix Table 2. Fruit Quality Attribute Comparisons of Rootstock within Watermelon Cultivars Used as Scions in 2004

		Firmness (N)						Lycopene (µg/g)						Soluble Solids (%)					
		Field 1600			Field 5100			Field 1600			Field 5100			Field 1600			Field 5100		
Cultivar	Root Stock	LS Mean		Std Err	LS Mean		Std Err	LS Mean		Std Err	LS Mean		Std Err	LS Mean		Std Err	LS Mean		Std Err
Jamboree	none	6.8	a	1.2	5.9	b	0.7	46.5	b	3.0	59.5	a	2.5	9.8	a	0.3	10.5	b	0.2
Jubilee	none	7.7	a	1.7	8.4	a	1.0	49.5	ab	4.1	46.4	b	2.8	10.0	a	0.4	9.7	c	0.3
Royal Sweet	none	8.1	a	1.3	4.5	b	0.9	45.2	b	3.1	43.6	b	2.5	10.0	a	0.3	10.7	ab	0.2
Sangria	none	7.6	a	1.4	8.0	a	0.6	59.0	a	3.5	59.2	a	1.9	10.5	a	0.3	11.1	a	0.2
SF800	none	8.1	b	1.4	9.9	a	0.7	63.5	a	3.3	69.3	ab	2.1	10.7	a	0.3	11.0	a	0.2
SF800	RS1330	11.8	a	1.2	10.5	a	0.9	51.5	b	3.0	75.0	ab	2.6	10.5	a	0.3	11.1	a	0.2
SF800	RS1332	9.3	ab	1.7	8.4	a	0.7	64.8	a	4.1	65.2	b	2.6	9.8	a	0.3	10.5	a	0.2
SF800	RS1420	11.3	ab	1.4	10.8	a	0.8	65.7	a	3.3	78.5	a	2.6	10.6	a	0.3	11.0	a	0.2
SF800	RS1421	10.1	ab	1.4	9.4	a	0.9	60.1	ab	3.5	74.0	ab	2.5	10.6	a	0.3	10.9	a	0.2
SS5244	none	10.3	b	1.0	7.0	b	0.7	55.4	ab	2.3	64.6	b	2.1	10.2	a	0.2	11.0	b	0.2
SS5244	RS1330	13.0	ab	0.9	11.6	a	0.7	61.6	a	2.2	74.4	a	2.0	10.0	ab	0.2	11.9	a	0.2
SS5244	RS1332	11.3	ab	1.5	10.7	a	0.8	65.6	a	3.8	64.2	b	2.2	9.9	ab	0.3	10.8	b	0.2
SS5244	RS1420	15.2	a	1.1	12.9	a	0.7	50.4	b	2.8	74.1	a	2.0	9.4	b	0.3	11.9	a	0.2
SS5244	RS1421	9.8	b	1.8	10.8	a	0.7	63.2	ab	4.4	75.2	a	2.0	10.4	ab	0.4	12.1	a	0.2
SS7167	none	13.3	bc	1.1	10.1	c	0.7	52.7	a	2.6	64.2	ab	2.0	9.5	a	0.2	11.3	ab	0.2
SS7167	RS1330	17.8	ab	0.8	13.7	ab	0.7	51.9	a	1.9	66.2	ab	2.0	9.8	a	0.2	11.7	ab	0.2
SS7167	RS1332	16.4	abc	1.0	13.0	ab	0.7	58.1	a	2.4	64.2	ab	2.1	9.9	a	0.2	11.3	ab	0.2

(Appendix Table 2). Contd…..

SS7167	RS1420	18.4	a	1.0	15.1	a	0.8	51.3	a	2.4	62.0	b	2.3	9.9	a	0.2	11.1	b	0.2
SS7167	RS1421	12.1	c	0.8	11.3	bc	0.7	52.6	a	1.9	71.9	a	2.1	10.2	a	0.2	11.9	a	0.2
SS7177	none	13.9	b	1.2	10.1	b	0.6	54.2	a	2.9	62.0	c	1.7	9.4	a	0.3	11.3	a	0.2
SS7177	RS1330	19.0	a	0.9	15.0	a	0.7	53.4	a	2.1	69.8	ab	2.0	10.4	a	0.2	11.5	a	0.2
SS7177	RS1332	14.2	ab	1.5	13.7	a	0.7	54.6	a	3.8	65.6	abc	2.1	9.6	a	0.3	11.3	a	0.2
SS7177	RS1420	18.9	a	1.0	16.3	a	0.7	59.1	a	2.4	72.6	a	2.0	10.2	a	0.2	11.5	a	0.2
SS7177	RS1421	13.8	b	1.4	15.0	a	0.7	49.8	a	3.3	63.3	bc	2.1	9.6	a	0.3	11.2	a	0.2
SS7187	none	14.5	a	1.1	10.7	c	0.7	58.2	a	2.6	59.3	a	2.0	10.1	a	0.2	11.6	a	0.2
SS7187	RS1330	15.0	a	1.4	15.9	ab	0.7	64.1	a	3.5	67.3	a	2.0	9.8	a	0.3	11.4	a	0.2
SS7187	RS1332	15.2	a	1.0	13.9	b	0.7	56.1	a	2.5	60.7	a	2.0	10.5	a	0.2	11.0	a	0.2
SS7187	RS1420	NT			19.2	a	1.2	NT			59.9	a	3.5	NT			10.6	a	0.3
SS7187	RS1421	12.7	a	1.8	14.4	b	0.7	65.1	a	4.4	61.1	a	2.0	10.3	a	0.4	11.2	a	0.2

Values in Table are least square means with pooled standard errors within cultivar groupings. Means followed by same letters within a cultivar group within a column are not significantly different at $P \leq 0.05$ using Tukey's adjusted means comparison.
NT: not tested.

Appendix Table 3. Fruit Quality Attribute Comparisons of Rootstock within Watermelon Cultivars Used as Scions in 2005

		Firmness (N)						Lycopene (µg/g)						Soluble Solids (%)					
		Field 1400			Field 5100			Field 1400			Field 5100			Field 1400			Field 5100		
Cultivar	**Root Stock**	**LS Mean**		**Std Err**	**LS Mean**		**Std Err**	**LS Mean**		**Std Err**	**LS Mean**		**Std Err**	**LS Mean**		**Std Err**	**LS Mean**		**Std Err**
Jamboree	none	7.5	a	0.7	7.9	a	0.7	47.5	b	2.2	64.5	a	2.5	11.7	a	0.2	11.8	ab	0.2
Jubilee	none	NT			7.9	a	1.0	NT			62.5	a	3.5	NT			11.2	b	0.3
RoyalSweet	none	7.8	a	0.9	6.2	b	0.8	45.2	b	3.1	58.5	a	2.8	11.6	a	0.3	12.3	a	0.2
Sangria	none	8.7	a	0.6	8.0	a	0.6	53.2	a	1.9	66.4	a	2.0	11.4	a	0.2	11.9	ab	0.2
SF_800	none	8.8	b	0.8	9.4	a	0.8	49.8	a	2.5	74.6	a	2.8	11.8	a	0.2	11.9	a	0.2
SF_800	RS1330	13.2	a	1.3	12.0	a	0.8	69.1	a	4.4	78.9	a	2.8	11.3	a	0.4	11.5	a	0.2
SF_800	RS1332	8.9	b	0.8	9.2	a	0.8	57.4	a	2.5	76.6	a	2.8	11.6	a	0.2	11.9	a	0.2
SF_800	RS1420	9.4	ab	0.9	11.9	a	0.8	53.7	a	3.1	72.0	a	2.8	12.0	a	0.3	11.8	a	0.2
SF_800	RS1422	9.4	ab	0.8	9.4	a	0.8	57.9	a	2.5	72.8	a	2.8	11.8	a	0.2	11.8	a	0.2
SS5244	none	8.9	a	0.8	8.7	a	0.8	56.6	a	2.5	76.1	ab	2.8	11.7	a	0.2	12.7	a	0.2
SS5244	RS1330	11.7	a	0.8	11.3	a	0.8	62.4	a	2.5	77.5	a	2.8	11.2	a	0.2	12.2	ab	0.2
SS5244	RS1332	8.8	a	0.8	9.1	a	0.8	58.0	a	2.5	75.9	ab	2.8	11.6	a	0.2	12.2	ab	0.2
SS5244	RS1420	11.4	a	0.9	11.0	a	0.8	64.2	a	3.1	76.8	ab	2.8	11.3	a	0.3	12.4	ab	0.2
SS5244	RS1422	9.4	a	0.9	9.6	a	0.8	56.8	a	3.1	68.8	b	2.8	11.6	a	0.3	11.7	b	0.2
SS7167	none	9.7	a	0.8	10.8	a	0.8	49.6	a	2.5	66.5	a	2.8	11.3	ab	0.2	12.4	ab	0.2
SS7167	RS1330	12.4	a	0.9	13.3	a	0.8	47.3	a	3.1	69.0	a	2.8	10.8	b	0.3	12.3	ab	0.2
SS7167	RS1332	11.4	a	0.8	10.0	a	0.8	47.1	a	2.5	61.3	a	2.8	10.9	ab	0.2	11.7	b	0.2
SS7167	RS1420	12.3	a	0.9	13.4	a	0.8	49.5	a	3.1	73.2	a	2.8	11.3	ab	0.3	12.3	ab	0.2
SS7167	RS1422	12.0	a	0.8	12.9	a	0.8	51.7	a	2.5	66.2	a	2.8	11.3	a	0.2	12.6	a	0.2

(Appendix Table 3). Contd…..

SS7177	none	12.1	b	0.8	10.9	a	0.8	50.3	a	2.5	68.3	a	2.8	11.3	a	0.2	11.6	a	0.2
SS7177	RS1330	15.4	a	0.8	13.1	a	0.8	51.7	a	2.5	72.1	a	2.8	9.9	b	0.2	11.5	a	0.2
SS7177	RS1332	12.3	ab	0.8	11.5	a	0.8	51.5	a	2.5	64.7	a	2.8	10.6	ab	0.2	11.3	a	0.2
SS7177	RS1420	14.3	ab	1.3	14.2	a	0.8	50.6	a	4.4	64.2	a	2.8	10.6	ab	0.4	11.1	a	0.2
SS7177	RS1422	11.8	b	0.8	11.8	a	0.8	56.8	a	2.5	70.6	a	2.8	11.1	a	0.2	11.5	a	0.2
SS7187	none	10.9	b	0.8	11.4	b	0.8	54.2	a	2.5	71.9	a	2.8	11.5	a	0.2	11.9	a	0.2
SS7187	RS1330	14.6	a	0.8	14.5	a	0.8	60.5	a	2.5	69.2	a	2.8	10.9	ab	0.2	11.6	a	0.2
SS7187	RS1332	10.9	b	0.8	10.8	b	0.8	51.1	a	2.5	67.3	a	2.8	10.8	ab	0.2	10.9	a	0.2
SS7187	RS1420	13.5	ab	0.9	14.6	a	0.8	57.7	a	3.1	70.5	a	2.8	10.4	b	0.3	11.0	a	0.2
SS7187	RS1422	12.4	ab	0.8	11.6	ab	0.8	54.1	a	2.5	70.0	a	2.8	11.1	ab	0.2	11.4	a	0.2

Values in Table are least square means with pooled standard errors within cultivar groupings. Means followed by same letters within a cultivar group within a column are not significantly different at P≤ 0.05 using Tukey's adjusted means comparison.
NT: not tested.

Appendix Table 4. Fruit Quality Attribute Comparisons of Watermelon Cultivars Used as Scions within Rootstocks in 2004

		Firmness						Lycopene (µg/g)						Soluble Solids (%)					
		Field 1600			Field 5100			Field 1600			Field 5100			Field 1600			Field 5100		
Root Stock	Cultivar	LS Mean		Std Err	LS Mean		Std Err	LS Mean		Std Err	LS Mean		Std Err	LS Mean		Std Err	LS Mean		Std Err
RS1330	SF800	11.8	b	1.2	10.5	c	0.9	51.5	ab	3.0	75.0	ab	2.6	10.5	a	0.3	11.1	b	0.2
RS1330	SS5244	13.0	b	0.9	11.6	bc	0.7	61.6	a	2.2	74.4	a	2.0	10.0	a	0.2	11.9	a	0.2
RS1330	SS7167	17.8	a	0.8	13.7	ab	0.7	51.9	b	1.9	66.2	c	2.0	9.8	a	0.2	11.7	ab	0.2
RS1330	SS7177	19.0	a	0.9	15.0	a	0.7	53.4	ab	2.1	69.8	abc	2.0	10.4	a	0.2	11.5	ab	0.2
RS1330	SS7187	15.0	ab	1.4	15.9	a	0.7	64.1	a	3.5	67.3	bc	2.0	9.8	a	0.3	11.4	ab	0.2
RS1332	SF800	9.3	b	1.7	8.4	c	0.7	64.8	a	4.1	65.2	a	2.6	9.8	a	0.3	10.5	b	0.2
RS1332	SS5244	11.3	ab	1.5	10.7	bc	0.8	65.6	a	3.8	64.2	a	2.2	9.9	a	0.3	10.8	ab	0.2
RS1332	SS7167	16.4	a	1.0	13.0	ab	0.7	58.1	a	2.4	64.2	a	2.1	9.9	a	0.2	11.3	a	0.2
RS1332	SS7177	14.2	ab	1.5	13.7	ab	0.7	54.6	a	3.8	65.6	a	2.1	9.6	a	0.3	11.3	ab	0.2
RS1332	SS7187	15.2	ab	1.0	13.9	a	0.7	56.1	a	2.5	60.7	a	2.0	10.5	a	0.2	11.0	ab	0.2
RS1420	SF800	11.3	b	1.4	10.8	c	0.8	65.7	a	3.3	78.5	a	2.6	10.6	a	0.3	11.0	b	0.2
RS1420	SS5244	15.2	ab	1.1	12.9	bc	0.7	50.4	b	2.8	74.1	a	2.0	9.4	b	0.3	11.9	a	0.2
RS1420	SS7167	18.4	a	1.0	15.1	ab	0.8	51.3	b	2.4	62.0	b	2.3	9.9	ab	0.2	11.1	b	0.2
RS1420	SS7177	18.9	a	1.0	16.3	ab	0.7	59.1	ab	2.4	72.6	a	2.0	10.2	ab	0.2	11.5	ab	0.2
RS1420	SS7187	NT			19.2	a	1.2	NT			59.9	b	3.5	NT			10.6	b	0.3
RS1421	SF800	10.1	a	1.4	9.4	b	0.9	60.1	ab	3.5	74.0	a	2.5	10.6	a	0.3	10.9	b	0.2
RS1421	SS5244	9.8	a	1.8	10.8	b	0.7	63.2	ab	4.4	75.2	a	2.0	10.4	a	0.4	12.1	a	0.2
RS1421	SS7167	12.1	a	0.8	11.3	b	0.7	52.6	ab	1.9	71.9	ab	2.1	10.2	a	0.2	11.9	a	0.2
RS1421	SS7177	13.8	a	1.4	15.0	a	0.7	49.8	b	3.3	63.3	bc	2.1	9.6	a	0.3	11.2	b	0.2
RS1421	SS7187	12.7	a	1.8	14.4	a	0.7	65.1	a	4.4	61.1	c	2.0	10.3	a	0.4	11.2	b	0.2
none	SF800	8.1	c	1.4	9.9	ab	0.7	63.5	a	3.3	69.3	a	2.1	10.7	a	0.3	11.0	a	0.2

(Appendix Table 4). Contd…..

none	SS5244	10.3	bc	1.0	7.0	b	0.7	55.4	a	2.3	64.6	ab	2.1	10.2	a	0.2	11.0	a	0.2
none	SS7167	13.3	ab	1.1	10.1	a	0.7	52.7	a	2.6	64.2	ab	2.0	9.5	a	0.2	11.3	a	0.2
none	SS7177	13.9	ab	1.2	10.1	a	0.6	54.2	a	2.9	62.0	ab	1.7	9.4	a	0.3	11.3	a	0.2
none	SS7187	14.5	a	1.1	10.7	a	0.7	58.2	a	2.6	59.3	b	2.0	10.1	a	0.2	11.6	a	0.2
none	Jamboree	6.8	a	1.2	5.9	b	0.7	46.5	b	3.0	59.5	a	2.5	9.8	a	0.3	10.5	b	0.2
none	Jubilee	7.7	a	1.7	8.4	a	1.0	49.5	ab	4.1	46.4	b	2.8	10.0	a	0.4	9.7	c	0.3
none	Royal Sweet	8.1	a	1.3	4.5	b	0.9	45.2	b	3.1	43.6	b	2.5	10.0	a	0.3	10.7	ab	0.2
none	Sangria	7.6	a	1.4	8.0	a	0.6	59.0	a	3.5	59.2	a	1.9	10.5	a	0.3	11.1	a	0.2

Values in the Table are least square means with pooled standard errors in rootstock groupings. Means followed by same letters within a cultivar group within a column are not significantly different at P≤0.05 using Tukey's adjusted means comparison.
NT: not tested.

Appendix Table 5. Fruit Quality Attribute Comparisons of Watermelon Cultivars Used as Scions within Rootstocks in 2005

		Firmness (N)						Lycopene (µg/g)						Sugar (%)					
		Field 1400			Field 5100			Field 1400			Field 5100			Field 1400			Field 5100		
Root Stock	Cultivar	LS Mean		Std Err	LS Mean		Std Err	LS Mean		Std Err	LS Mean		Std Err	LS Mean		Std Err	LS Mean		Std Err
RS1330	SF800	13.2	a	1.3	12.0	a	0.8	69.1	a	4.4	78.9	a	2.8	11.3	ab	0.4	11.5	a	0.2
RS1330	SS5244	11.7	a	0.8	11.3	a	0.8	62.4	a	2.5	77.5	a	2.8	11.2	a	0.2	12.2	a	0.2
RS1330	SS7167	12.4	a	0.9	13.3	a	0.8	47.3	c	3.1	69.0	a	2.8	10.8	ab	0.3	12.3	a	0.2
RS1330	SS7177	15.4	a	0.8	13.1	a	0.8	51.7	bc	2.5	72.1	a	2.8	9.9	b	0.2	11.5	a	0.2
RS1330	SS7187	14.6	a	0.8	14.5	a	0.8	60.5	ab	2.5	69.2	a	2.8	10.9	ab	0.2	11.6	a	0.2
RS1332	SF800	8.9	b	0.8	9.2	a	0.8	57.4	a	2.5	76.6	a	2.8	11.6	a	0.2	11.9	ab	0.2
RS1332	SS5244	8.8	b	0.8	9.1	a	0.8	58.0	a	2.5	75.9	a	2.8	11.6	a	0.2	12.2	a	0.2
RS1332	SS7167	11.4	ab	0.8	10.0	a	0.8	47.1	a	2.5	61.3	b	2.8	10.9	ab	0.2	11.7	ab	0.2
RS1332	SS7177	12.3	a	0.8	11.5	a	0.8	51.5	a	2.5	64.7	ab	2.8	10.6	b	0.2	11.3	ab	0.2
RS1332	SS7187	10.9	ab	0.8	10.8	a	0.8	51.1	a	2.5	67.3	ab	2.8	10.8	ab	0.2	10.9	b	0.2
RS1420	SF800	9.4	a	0.9	11.9	a	0.8	53.7	a	3.1	72.0	a	2.8	12.0	a	0.3	11.8	ab	0.2
RS1420	SS5244	11.4	a	0.9	11.0	a	0.8	64.2	a	3.1	76.8	a	2.8	11.3	a	0.3	12.4	a	0.2
RS1420	SS7167	12.3	a	0.9	13.4	a	0.8	49.5	a	3.1	73.2	a	2.8	11.3	a	0.3	12.3	a	0.2
RS1420	SS7177	14.3	a	1.3	14.2	a	0.8	50.6	a	4.4	64.2	a	2.8	10.6	a	0.4	11.1	b	0.2
RS1420	SS7187	13.5	a	0.9	14.6	a	0.8	57.7	a	3.1	70.5	a	2.8	10.4	a	0.3	11.0	b	0.2
RS1422	SF800	9.4	c	0.8	9.4	a	0.8	57.9	a	2.5	72.8	a	2.8	11.8	a	0.2	11.8	ab	0.2
RS1422	SS5244	9.4	bc	0.9	9.6	a	0.8	56.8	a	3.1	68.8	a	2.8	11.6	ab	0.3	11.7	ab	0.2
RS1422	SS7167	12.0	ab	0.8	12.9	a	0.8	51.7	a	2.5	66.2	a	2.8	11.3	ab	0.2	12.6	a	0.2
RS1422	SS7177	11.8	abc	0.8	11.8	a	0.8	56.8	a	2.5	70.6	a	2.8	11.1	ab	0.2	11.5	ab	0.2
RS1422	SS7187	12.4	a	0.8	11.6	a	0.8	54.1	a	2.5	70.0	a	2.8	11.1	b	0.2	11.4	b	0.2
none	SF800	8.8	c	0.8	9.4	ab	0.8	49.8	a	2.5	74.6	a	2.8	11.8	a	0.2	11.9	b	0.2

(Appendix Table 5). Contd…..

none	SS5244	8.9	bc	0.8	8.7	b	0.8	56.6	a	2.5	76.1	a	2.8	11.7	a	0.2	12.7	a	0.2
none	SS7167	9.7	bc	0.8	10.8	ab	0.8	49.6	a	2.5	66.5	a	2.8	11.3	a	0.2	12.4	ab	0.2
none	SS7177	12.1	a	0.8	10.9	ab	0.8	50.3	a	2.5	68.3	a	2.8	11.3	a	0.2	11.6	b	0.2
none	SS7187	10.9	ab	0.8	11.4	a	0.8	54.2	a	2.5	71.9	a	2.8	11.5	a	0.2	11.9	b	0.2
none	Jamboree	7.5	a	0.7	7.9	a	0.7	47.5	b	2.2	64.5	a	2.5	11.7	a	0.2	11.8	ab	0.2
none	Jubilee	NT			7.9	a	1.0	NT			62.5	a	3.5	NT			11.2	b	0.3
none	Royal Sweet	7.8	a	0.9	6.2	b	0.8	45.2	b	3.1	58.5	a	2.8	11.6	a	0.3	12.3	a	0.2
none	Sangria	8.7	a	0.6	8.0	a	0.6	53.2	a	1.9	66.4	a	2.0	11.4	a	0.2	11.9	ab	0.2

Values in Table are least square means with pooled standard errors in rootstock groupings. Means followed by same letters within a cultivar group within a column are not significantly different at P≤ 0.05 using Tukey's adjusted means comparison.
NT: not tested.

Watermelon production has become more sophisticated in the past thirty years as the industry has evolved from open-pollinated diploids to hybrid diploids and ultimately to triploids with diploid pollinator plants [3]. The fresh-cut industry in the United States has grown dramatically in the last 10 years and makes up almost 30% of the total watermelon sold (National Watermelon Promotion Board, personal communication). While watermelon may be purchased as halves or quarters with a portion of the rind remaining, most of the fresh-cut watermelon is sold as small chunks (without rind) in plastic containers where fruit firmness is a major concern for extended shelf-life. In addition to achieving increased disease resistance in the plant, the enhanced fruit firmness of grafted watermelon fruit may contribute significantly to the fresh-cut industry.

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