Research Article

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Instrumental and sensory analyses of quality attributes of grafted specialty melons

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Abstract

BACKGROUND: Soilborne disease management remains a great challenge in melon production with the phaseout of soil fumigant methyl bromide. Grafting has been shown to be an effective approach to control soilborne diseases. However, previous research has yielded mixed results regarding the impacts of rootstock on fruit quality. Very few studies have assessed melon quality attributes using both sensory evaluation and instrumental methods.

RESULTS: Galia melon 'Arava' (*Cucumis melo* L. var. *reticulatus* Ser.) and honeydew melon 'Honey Yellow' (*C. melo* L. var. *inodorus* Naud.) were grafted onto commercial hybrid squash (*Cucurbita maxima* Duchesne × *Cucurbita moschata* Duchesne) rootstocks and root-knot nematode-resistant *Cucumis metulifer* E. Mey. ex Naud. rootstock. The grafting combinations were evaluated under different production conditions. Grafting with hybrid squash rootstocks resulted in reduced soluble solids content (SSC) and decreased sensory ratings of 'Arava' fruit. By contrast with grafted 'Arava', grafted 'Honey Yellow' did not exhibit significant differences in sensory properties and instrumental measurements regardless of production conditions and rootstock selection.

CONCLUSION: The effects of grafting on fruit quality attributes differed between the two distinctive types of melon scion used. Potential negative impacts of rootstocks on melon fruit quality need to be considered in the selection and use of disease-resistant rootstocks.

Keywords: *Cucumis melo* L.; rootstock; soluble solids content; firmness; acceptance testing; hedonic

INTRODUCTION

Cantaloupes as well as specialty melons (*Cucumis melo* L.) account for an important component of fresh consumed vegetables and fruits in the USA.[1,2] However, phaseout of methyl bromide as a broad-spectrum soil fumigant brought melon production considerable challenges.[3] In order to maintain high yield and meet domestic demand, there is a critical need for innovative and integrated practices for controlling soilborne pests. Although relatively new in the USA, vegetable grafting has been used in Asian and European countries for decades mainly for soilborne disease management in cucurbit and solanaceous crops.[4–6] The grafted plant combines a scion plant with desirable horticultural characteristics and a rootstock plant that is resistant to target diseases. Several soilborne diseases can be managed through grafting.[4–6] Grafted plants have also shown improved abiotic stress tolerance and enhanced water and nutrient uptake.[6,7] As interest in melon grafting is growing in the USA, its impacts on fruit quality are gaining more attention. This is particularly true for specialty melons, as they are usually marketed for unique fruit flavor and outstanding eating quality.

Previous studies on melon grafting generated contradictory results with respect to fruit quality attributes. The rootstock and scion combination is one of the major factors contributing to the mixed results. For example, hybrid squash rootstock 'RS841' (*Cucurbita maxima* Duchesne × *Cucurbita moschata* Duchesne) exhibited no impact on the total soluble solids content (SSC) of melon fruit 'Incas' (*C. melo* L. var. *inodorus* Naud.),[8] but the same rootstock reduced the SSC of 'Piñonet Torpedo' melons (*C. melo* var. *inodorus*).[9] With the same scion cultivars, different rootstocks might exhibit different impacts. 'Supermarket' and 'Proteo' melons (*C. melo* var. *reticulatus*) were grafted onto eight rootstocks in a two-year study. The SSC of the two melon cultivars was not affected by *C. maxima* × *C. moschata* rootstock, while it was reduced by grafting with *Benincasa hispida* (Thunb.) Cogn. rootstock.[10] Production conditions are another factor that may affect the quality attributes of fruit from grafted melon plants.[10,11] Moreover, grafting might influence fruit ripening behavior. If fruits from grafted and non-grafted control plants were harvested simultaneously, it is likely that the differences in quality assessment could be a reflection of harvest maturity.[12]

Fruit quality is a multivariate characteristic, and SSC and flesh firmness are among the most important quality attributes used for assessing grafted melon quality.[13,14] Other quality-related attributes including preharvest internal decay, internal breakdown, fibrous flesh and poor netting were found associated with fruit of grafted melons in comparison with their non-grafted counterparts in early Japanese and Korean literature.[15] As the roles of

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aroma volatiles and health-related compounds in the determination of melon fruit quality are increasingly recognized, grafting effects on these characteristics were also studied.[16–20] In addition, reduced fruit shelf-life following 1-methylcyclopropene treatment was found in cantaloupe 'Athena' grafted onto 'Tetsukabuto' rootstocks (*C. maxima* × *C. moschata*).[21]

Sensory evaluation involves the interpretation of sensory experiences by humans and can provide accurate predictions of how humans are likely to react to the fruit.[22] Meanwhile, sensory evaluation provides an approach to study different quality variables and their impacts on perceived sensory attributes in an integrated manner. Hence replacing sensory evaluation with individual instrumental measurement is often not feasible,[23] while substitution of instrumental measurements for sensory tests did not always work well.[24,25] It has been suggested that the overall evaluation of melon fruit quality should combine both instrumental measurements and sensory analysis.[25]

Melon quality attributes as influenced by cultivar, ripening stage and postharvest treatment were evaluated by combining sensory analysis and instrumental measurements.[26–29] However, very few studies assessing fruit quality of grafted melons involved well-designed acceptance sensory testing. Reliable acceptance testing normally involves 75–150 consumer panelists. A nine-point hedonic scale is one of the most valid and reliable scales used in acceptance testing.[30]

In this study, grafted specialty melons with different rootstock and scion combinations were grown under three different production systems. Using both acceptance sensory evaluation and instrumental measurements, quality attributes of grafted specialty melons were determined with the overall goal of enhancing our comprehensive understanding of rootstock-induced grafting impacts on melon quality.

EXPERIMENTAL

Melon production

The field experiments were conducted in the spring seasons of 2012 and 2013 at the University of Florida Plant Science Research and Education Unit in Citra, FL, USA. In 2012, galia melon 'Arava' (*C. melo* L. var. *reticulatus* Ser.) and honeydew melon 'Honey Yellow' (*C. melo* L. var. *inodorus* Naud.) were grafted onto each of the two rootstocks: hybrid squash 'Strong Tosa' (*C. maxima* Duchesne × *C. moschata* Duchesne) and *Cucumis metulifer* E. Mey. ex Naud. Seeds of the two melon scions were purchased from Johnny's Selected Seeds (Winslow, ME, USA). Hybrid squash rootstock seeds were donated by Syngenta Seeds (Minnetonka, MN, USA), and *C. metulifer* rootstock seeds were provided by the USDA ARS Vegetable Laboratory (Charleston, SC, USA). Non-grafted and self-grafted melon plants were included as controls. Grafted plants and controls were evaluated in three production systems: certified organic production (Quality Certification Services, Gainesville, FL, USA), conventional production with soil fumigation and conventional production without soil fumigation. Specific treatments in each of the three production systems are listed in Table 1. Based on the findings from the 2012 studies with respect to the effects of hybrid squash rootstock on fruit quality of 'Arava', only 'Arava' melon scion was evaluated in the 2013 study. 'Arava' was grafted onto 'Strong Tosa' rootstock and another hybrid squash rootstock 'Carnivor' (*C. maxima* Duchesne × *C. moschata* Duchesne) (seeds donated by Syngenta Seeds). Grafted and non-grafted controls were planted in the fumigated conventional field in 2013.

Table 1. Grafting treatments included in certified organic field, non-fumigated conventional field and fumigated conventional field in spring 2012

Production practice		Scion: 'Arava'	Scion: 'Honey Yellow'
Fumigated conventional	Rootstock	'Strong Tosa'	'Strong Tosa'
		'Arava' (self-grafted)	'Honey Yellow' (self-grafted)
		Non-grafted	Non-grafted
Non-fumigated conventional	Rootstock	*C. metulifer*	*C. metulifer*
		'Strong Tosa'	'Strong Tosa'
		Non-grafted	Non-grafted
Certified organic	Rootstock	*C. metulifer*	*C. metulifer*
		'Arava' (self-grafted)	'Honey Yellow' (self-grafted)
		Non-grafted	Non-grafted

'Strong Tosa' was only included in the conventional systems because the seeds were treated with fungicide. *Cucumis metulifer* was included in the non-fumigated conventional and certified organic systems owing to its potential for soilborne disease control.

The fumigated conventional system was used to minimize the influence of soilborne diseases on plant performance.

Conventional and organic transplants were produced as described previously.[31] Grafting was conducted using the one-cotyledon method.[32] Plants were transplanted in the field at the three-true-leaf stage on 29 March and 10 April in 2012 and 2013 respectively. The soil fumigant methyl bromide/chloropicrin (50:50 w/w) was applied at a rate of 448 kg ha^{-1} three weeks before transplanting in the conventional field. The non-fumigated conventional field was treated with halosulfuron-methyl (Sandea, Gowan Company, Yuma, AZ, USA) for nutsedge control one week before transplanting, at a rate according to the product label. Production practices in both organic and conventional fields were followed as described previously.[31] Experiments were arranged in a randomized complete block design with five replications (blocks) in 2012 and four replications (blocks) in 2013. Eight plants were included per treatment per replication.

Harvests lasted from 21 May to 14 June in 2012 and from 6 to 20 June in 2013. 'Arava' was harvested at the full-slip stage, and 'Honey Yellow' was harvested based on external fruit color. The color stage selected as a harvesting index for 'Honey Yellow' equated to an SSC of 16% at the first harvest.[31]

Fruit selection for sensory analyses

Analyses of the two melon cultivars were conducted separately on different days. Each cultivar was analyzed twice in the 2012 harvest season (1 and 12 June for 'Arava' and 25 May and 13 June for 'Honey Yellow'). The day before sensory analysis, melons were harvested and stored overnight at 10 °C. Ten fully ripe melons were chosen from each treatment based on fruit size, approximately 1.5 kg per fruit, and absence of defects. Six treatments were included in each of the analyses. The first analysis included melons produced from the fumigated conventional field (i.e. fruit of non-grafted, self-grafted and 'Strong Tosa' rootstock-grafted melon plants) and the organic field (i.e. fruit of non-grafted, self-grafted and *C. metulifer* rootstock-grafted melon plants). The second analysis assessed melons from the fumigated and

non-fumigated conventional fields (i.e. fruit of non-grafted and 'Strong Tosa' and *C. metulifer* rootstock-grafted melon plants). In 2013, one sensory analysis with three treatments, i.e. non-grafted 'Arava', 'Arava' grafted onto 'Strong Tosa' rootstock and 'Arava' grafted onto 'Carnivor' rootstock, was conducted on June 14.

Sensory analyses

On the day of sensory analysis, melon fruits were washed in tap water and dried with paper towels. They were then cut longitudinally into halves. Half of the samples were used for sensory analysis while the remaining counterparts were used for instrumental measurements (described below). Rinds and contiguous flesh (~1.5 cm) of the melon halves were discarded. The melon flesh, consisting largely of mesocarp, was cut into roughly 3 cm × 3 cm × 3 cm cubes. Fruit cubes from ten halves of each treatment were mixed and held in a plastic container at 4 °C prior to and during the sensory tests, which typically lasted 5 h.

Acceptance sensory tests were conducted at the University of Florida Sensory Analysis Lab in Gainesville, FL, USA. The procedures of the acceptance sensory tests and layout of the sensory analysis lab were followed as described previously.[33] Each of the sensory tests had 96–100 untrained panelists. They consisted largely of students, faculty and staff members on campus who reported prior experience in consuming melons. Six samples with two melon cubes of each sample were randomly arranged and presented to panelists. Panelists were first asked to answer demographic questions including gender, age and melon consumption frequency. For each sample, panelists were asked to score overall acceptability, firmness liking and flavor liking using a 1–9 hedonic scale (i.e. 9 = like extremely, 5 = neither like nor dislike, 1 = dislike extremely). The panelists were then asked to describe the firmness and sweetness levels using a 1–5 Just-About-Right scale (i.e. 1 = too soft/not sweet at all, 2 = slightly too soft/not quite sweet enough, 3 = just about right, 4 = slightly too firm/somewhat too sweet, 5 = too firm/much too sweet).[22]

Instrumental measurements

Flesh firmness and SSC were measured in the 2012 samples, while flesh firmness, SSC, titratable acidity and pH were measured in the 2013 samples. Flesh firmness and SSC were measured at two points in the equatorial region of the mesocarp of each melon half. A hand-held penetrometer (Fruit Tester 10; Wagner Instruments, Greenwich, CT, USA) with an 8 mm diameter probe and a refractometer (AR200; Reichert Technologies, Depew, NY, USA) were used to measure flesh firmness and SSC respectively. Titratable acidity and pH were measured using a 719 S Titrino (Metrohm USA Inc., Riverview, FL, USA) following the methods described previously.[21]

Statistical analyses

Analysis of variance was performed using the Proc Glimmix procedure of the SAS program (Version 9.2 C for Windows, SAS Institute, Cary, NC, USA). Tukey's honest significant difference test ($\alpha = 0.05$) was conducted for multiple comparisons of different measurements among treatments.

RESULTS AND DISCUSSION

Regardless of production systems and rootstocks, total yield and fruit number of grafted 'Arava' and 'Honey Yellow' were not significantly different from those of non-grafted and self-grafted plants in 2012 (unpublished data).[31] Similar results were also observed in 2013 for grafted 'Arava' plants (unpublished data). The lack of yield difference among treatments in this study allowed for a more precise assessment of fruit quality as affected by grafting with different rootstocks.

Table 2. Sensory evaluation and instrumental measurements of grafted and non-grafted 'Arava' melon fruit in spring 2012

	Sensory evaluation[b]			Instrumental measurement	
Treatment[a]	Overall acceptability	Flavor liking	Firmness liking	SSC (°Brix)	Flesh firmness (kgf)
Test 1[c]					
F NGAr	6.51a[d]	6.32a	6.46a	11.43a	1.49a
F Ar/Ar	6.17a	6.07a	6.17ab	11.51a	1.25ab
F Ar/ST	5.39bc	5.20bc	5.79b	9.61b	1.20ab
O NGAr	5.97ab	5.62ab	5.95ab	7.62c	0.95b
O Ar/Ar	5.04c	4.72c	5.80b	7.32c	1.02b
O Ar/Cm	5.04c	4.78c	5.73b	7.74c	0.93b
P value	<0.0001	<0.0001	0.0059	<0.0001	<0.0001
Test 2[c]					
F NGAr	6.36a	6.36a	5.88ab	10.07a	1.17
F Ar/Ar	5.74bc	5.47bc	5.77ab	9.03ab	1 31
F Ar/ST	5.55 cd	5.24 cd	5.59b	8.72b	1.29
NF NGAr	6.18ab	5.95ab	6.21a	9.81a	1.55
NF Ar/Cm	5.72bc	5.42bc	5.82ab	9.60ab	1.18
NF Ar/ST	5.12d	4.81d	5.39b	8.82b	1.28
P value	<0.0001	<0.0001	0.0012	0.0008	0.3308

[a] NGAr, non-grafted 'Arava'; Ar/Ar, self-grafted 'Arava'; Ar/ST, 'Arava' grafted onto 'Strong Tosa' rootstock; Ar/Cm, 'Arava' grafted onto *C. metulifer* rootstock; F, fumigated conventional field; NF, non-fumigated conventional field; O, certified organic field.
[b] Attributes were evaluated on a nine-point hedonic scale: 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely.
[c] Tests 1 and 2 were conducted on 1 and 12 June 2012 respectively. Test 1 included 96 panelists and test 2 included 100 panelists.
[d] Means within a column followed by the same letter were not significantly different by Tukey's honest significant difference test at $P \leq 0.05$.

Fruit quality of 'Arava' grafted onto hybrid squash rootstocks

Consistent among all evaluated production systems in 2012 and 2013, the 'Arava' scion grafted onto 'Strong Tosa' rootstock (Ar/ST) reduced overall acceptability and flavor liking compared with non-grafted (NGAr) and self-grafted (Ar/Ar) 'Arava' (Table 2). Averaged across production conditions in 2012, panelists who scored the sweetness level as 'just about right' for Ar/ST were 19% lower than for NGAr, while 26% more panelists considered that the sweetness level of Ar/ST was either 'not sweet at all' or 'not quite sweet enough' (Table 3). As the Just-About-Right scale provided directional information for the hedonic questions,[34] the results suggested a reduced panelist liking of the Ar/ST melons because they were not sweet enough. This was further confirmed by the instrumental measurement. SSC was significantly lower in the flesh of Ar/ST compared with NGAr (Table 2). Similar rootstock effects were observed in the 'Arava' scions grafted onto 'Strong Tosa' and 'Carnivor' rootstocks in 2013, which reduced overall acceptability, flavor liking and SSC compared with NGAr (Table 4).

Table 3. Percentage distribution of panelists in sensory evaluation of sweetness and firmness levels in spring 2012

	Sweetness level (%)[b]					Firmness level (%)[b]				
Treatment[a]	1	2	3	4	5	1	2	3	4	5
Test 1[c]										
F NGAr	2.1	16.8	63.2	13.7	4.2	2.1	13.7	68.4	13.7	2.1
F Ar/Ar	2.1	25.3	52.6	15.8	4.2	4.2	29.5	55.8	9.5	1.1
F Ar/ST	7.4	37.9	44.2	10.5	0.0	4.2	40.0	48.4	6.3	1.1
O NGAr	13.7	42.1	42.1	2.1	0.0	5.3	34.7	51.6	8.4	0.0
O Ar/Ar	30.5	46.3	23.2	0.0	0.0	7.4	29.5	53.7	8.4	1.1
O Ar/Cm	21.1	51.6	25.3	2.1	0.0	5.3	28.4	50.5	13.7	2.1
Test 2[c]										
F NGAr	3.0	24.2	61.6	8.1	3.0	10.1	22.2	57.6	9.1	1.0
F Ar/Ar	13.1	41.4	39.4	5.1	1.0	9.1	19.2	51.5	19.2	1.0
F Ar/ST	8.1	43.4	42.4	6.1	0.0	3.0	29.3	49.5	15.2	3.0
NF NGAr	5.1	38.4	46.5	8.1	2.0	2.0	20.2	58.6	15.2	4.0
NF Ar/Cm	5.1	50.5	38.4	6.1	0.0	6.1	28.3	54.6	8.1	3.0
NF Ar/ST	16.2	54.6	27.3	2.0	0.0	4.0	18.2	48.5	23.2	6.1

[a] NGAr, non-grafted 'Arava'; Ar/Ar, self-grafted 'Arava'; Ar/ST, 'Arava' grafted onto 'Strong Tosa' rootstock; Ar/Cm, 'Arava' grafted onto *C. metulifer* rootstock; F, fumigated conventional field; NF, non-fumigated conventional field; O, certified organic field.
[b] Firmness and sweetness levels were evaluated with a Just-About-Right scale: 1 = too soft/not sweet at all, 2 = slightly too soft/not quite sweet enough, 3 = just about right, 4 = slightly too firm/somewhat too sweet, 5 = too firm/much too sweet.
[c] Tests 1 and 2 were conducted on 1 and 12 June 2012 respectively. Test 1 included 96 panelists and test 2 included 100 panelists.

Table 4. Sensory evaluation and instrumental measurements of grafted and non-grafted 'Arava' melons grown in fumigated conventional field in spring 2013

	Sensory evaluation[b]			Instrumental measurement			
Treatment[a]	Overall acceptability	Flavor liking	Firmness liking	SSC (°Brix)	Flesh firmness (kgf)	Titratable acidity	pH
NGAr	6.89a[c]	6.87a	6.57a	9.56a	1.02b	0.052	6.85
Ar/Ca	5.12b	4.69b	6.01b	5.77b	1.22a	0.046	6.78
Ar/ST	4.83b	4.33b	5.69b	5.72b	1.03b	0.052	6.72
P value	<0.0001	<0.0001	0.0001	<0.0001	0.0446	0.2386	0.1903

[a] NGAr, non-grafted 'Arava'; Ar/Ca, 'Arava' grafted onto 'Carnivor' rootstock; Ar/ST, 'Arava' grafted onto 'Strong Tosa' rootstock.
[b] Attributes were evaluated on a nine-point hedonic scale: 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely. This sensory test included 105 panelists.
[c] Means within a column followed by the same letter were not significantly different by Tukey's honest significant difference test at $P \leq 0.05$.

Hybrid squash rootstocks are well known for their vigorous root systems and the great potential for promoting growth vigor of scion plants.[32] Water status of the grafted melon plants could be enhanced as indicated by improved leaf water potential, leaf stomata conductance, transpiration rate and amount of xylem sap.[35,36] Thus the reduced SSC was suspected to be a consequence of water dilution effect.[37,38] We observed that 'Arava' scion grafted onto hybrid squash rootstocks exhibited delayed anthesis of female flowers, although the initial harvest period based on full-slip was unaffected (unpublished data). As fruit sugar levels tend to be positively correlated with the duration of fruit development period,[39,40] it is likely that the accelerated development of grafted melons could also partially explain the reduced SSC.

Perceived sweetness can be affected by presence of specific aroma,[41] thus the detected differences in sweetness level among grafting treatments might be related to effects of rootstock on melon volatile composition. More than 240 volatile compounds have been identified in muskmelon fruit,[42] and these volatiles and their unique combinations contribute to melon flavors. Interestingly, (*Z*)-3-nonen-1-ol and 2-phenyl ethanol that were described as sweet and floral in 'Proteo' melon (*C. melo* var. *reticulatus*) were below detectable threshold in grafted fruit, while herbal and green volatile (*E*)-3-hexen-1-ol was detected only in grafted fruit.[18] Although differences in volatile composition have been detected between grafted and control plants,[16–18] the effects of grafting on the synthesis and metabolism of fruit volatiles remain largely unknown.

Except for the fumigated conventional melons that were evaluated in the second sensory test, firmness liking of non-grafted 'Arava' was significantly higher than that of 'Arava' grafted onto hybrid squash rootstocks in the 2012 studies, whereas no significant differences in firmness were detected by the instrumental measurement (Table 2). Similar results from the sensory evaluation were observed in the 2013 study when 'Arava' was grafted with the two hybrid squash rootstocks 'Carnivor' and 'Strong Tosa'. However, the flesh firmness of 'Arava' grafted onto 'Carnivor' was higher than that of non-grafted 'Arava', while titratable acidity and pH did not differ between grafted and non-grafted treatments (Table 4). Since untrained panelists generally evaluate products

on the integrated pattern of sensory stimulation, they lack the capability to separate individual product attributes.[22] Accordingly, panelists may establish a positive relationship between two unrelated attributes such as sweetness and firmness.[43] Therefore the higher rating on firmness liking of non-grafted 'Arava' may reflect the fact that panelists preferred its sweetness more than that of fruit from the grafted treatments. Another potential explanation could be that texture attributes other than firmness, including juiciness and adhesiveness, were affected by grafting.[44] Even though panelists were not asked to rate these attributes, they nonetheless may have influenced panelist ratings on firmness liking.[22]

Fruit quality of 'Arava' grafted onto *C. metulifer* rootstock

For the organically produced 'Arava' melons, grafting with *C. metulifer* (Ar/Cm) decreased overall acceptability and flavor liking compared with NGAr. Interestingly, the self-grafted (Ar/Ar) control also showed lower scores of overall acceptability and flavor liking. However, negative effects of rootstock and grafting on sensory properties were not detected in fruit from non-fumigated conventional production. No differences in SSC and flesh firmness between NGAr, Ar/Ar and Ar/Cm were detected under either of the production systems (Table 2).

Known for root-knot nematode and fusarium wilt resistances, *C. metulifer* has been tested as a rootstock for grafting melons.[31,45–47] However, unlike some of the hybrid squash rootstocks, which enhanced fruit yield under certain stress conditions, the improvement of soilborne disease resistance from using *C. metulifer* rootstock did not lead to an increase in fruit yield.[10,31] Poor rootstock vigor may be part of the reason,[31] and it is likely that the mechanisms by which *C. metulifer* affects fruit quality differ from those of hybrid squash rootstocks. Melons grown in the organic and non-fumigated conventional fields yielded different results in the sensory analyses. This could indicate that the rootstock effects on melon fruit quality were influenced by environmental conditions. Year-to-year variation in fruit quality of 'Proteo' (*C. melo* var. *reticulatus*) grafted onto *C. metulifer* was also reported.[10] In the present study, *C. metulifer* rootstock did not affect SSC and flesh firmness measurements, indicating that its effects on sensory properties might be attributed to quality attributes other than sweetness and firmness.

Fruit quality of grafted 'Honey Yellow'

Regardless of production conditions and rootstock selection, grafted 'Honey Yellow' did not exhibit significant differences in sensory properties (including overall acceptability, flavor liking and firmness liking) and measurements of SSC and flesh firmness in comparison with non-grafted and self-grafted 'Honey Yellow' fruit (Table 5). Our findings agree with previous reports of insignificant influence of grafting on quality attributes of honeydew melons 'Lefko Amynteou'[11] and 'Incas'.[8] However, unsuitable rootstock can reduce the quality of 'Incas' fruit.[20]

We noted distinct differences in grafting effects on fruit quality in the honeydew and galia melon cultivars. One of the fundamental differences between the two melon cultivars is the fruit ripening pattern.[48] Galia melon 'Arava' is a climacteric fruit that exhibits autocatalytic ethylene production during fruit ripening. By contrast, honeydew melons exhibit a non-climacteric ripening pattern, with little change in ethylene production during ripening.[2,49] As many aroma compounds are only produced through ethylene-dependent pathways, climacteric melons are generally more aromatic than non-climacteric types.[50] Because climacteric galia melons are rich in aroma components, sensory properties are more likely to be affected by grafting practice than would be the case for the comparatively low-aromatic honeydew melons.

Although rootstock, scion and rootstock × scion interaction all contribute to fruit quality, the results of the present study indicate that the scion might play a more critical role in the process, especially considering the various types of specialty melon on the market. Similar observations were reported in a previous grafting study with four melon scions and three rootstocks (two commercial *Cucurbita* spp. hybrid rootstocks and one landrace of *C. moschata* rootstock). It was shown that fruit sensory properties of honeydew melon scion 'Lefko Amynteou' were generally not affected regardless of the rootstocks used, whereas taste and texture of some other melon cultivars were deteriorated after grafting with some of the same rootstocks.[11] A study using three cherry cultivars grafted onto five rootstocks with different size-controlling effects found that the scion accounted for the highest percentage of variation in quality modification, and it was concluded that fruit quality was more of a scion-dependent characteristic.[51] In citrus, it was also observed that some cultivars may be naturally high in quality, thus grafting practice as well as rootstock choice may be less influential in these cultivars compared with low-quality cultivars.[52]

Table 5. Sensory evaluation and instrumental measurements of grafted and non-grafted 'Honey Yellow' melon fruit in spring 2012

	Sensory evaluation[b]			Instrumental measurement	
Treatment[a]	Overall acceptability	Flavor liking	Firmness liking	SSC (°Brix)	Flesh firmness (kgf)
Test 1[c]					
F NGHY	6.00	5.74	5.85	15.07	2.83
F HY/HY	6.10	5.96	6.09	14.22	2.71
F HY/ST	5.98	5.81	6.08	14.20	2.59
O NGHY	6.18	6.14	5.92	14.80	2.87
O HY/HY	6.04	6.02	5.74	14.12	2.87
O HY/Cm	5.95	5.77	5.95	14.47	3.19
P value	NS[d]	NS	NS	NS	NS
Test 2[c]					
F NGHY	6.28	6.41	5.94	14.48	2.82
F HY/HY	6.06	6.05	5.62	15.42	2.82
F HY/ST	5.91	5.88	5.92	13.65	3.06
NF NGHY	6.05	6.06	6.04	14.73	3.06
NF HY/Cm	6.11	6.03	6.05	14.70	3.19
NF HY/ST	6.03	5.98	6.13	14.01	3.06
P value	NS[d]	NS	NS	NS	NS

[a] NGHY, non-grafted 'Honey Yellow'; HY/HY, self-grafted 'Honey Yellow'; HY/ST, 'Honey Yellow' grafted onto 'Strong Tosa' rootstock; HY/Cm, 'Honey Yellow' grafted onto *C. metulifer* rootstock; F, fumigated conventional field; NF, non-fumigated conventional field; O, certified organic field.
[b] Attributes were evaluated on a nine-point hedonic scale: 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely.
[c] Tests 1 and 2 were conducted on 25 May and 13 June 2012 respectively. Test 1 included 97 panelists and test 2 included 98 panelists.
[d] NS, non-significant, i.e. $P > 0.05$.

CONCLUSION

Combining sensory analysis and instrumental measurements provided a thorough evaluation of the effects of grafting on the quality attributes of specialty melons. Reduced SSC may be the primary reason for lower sensory properties of galia melon 'Arava' fruit when plants were grafted with the hybrid squash rootstocks. Environmental influences on fruit quality variation of 'Arava' grafted onto *C. metulifer* rootstock deserve future investigations. Compared with non-grafted honeydew melon 'Honey Yellow' fruit, grafted 'Honey Yellow' did not exhibit significant differences in fruit sensory properties and instrumental measurements. The differential responses of the two specialty melon types to grafting practice in terms of fruit quality warrant further investigations. More in-depth studies, especially those involving flavor-related volatile compounds and profiles as well as their biosynthetic pathways, are also warranted to improve our understanding of effects of rootstock and scion interactions on fruit quality and sensory properties of grafted melon fruit.

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