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Within-Season Volatile and Quality Differences in Stored Fresh-Cut Cantaloupe Cultivars

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Cantaloupe cultivar variability from various U.S. regions and growing seasons within a given year was evaluated. As expected, there was often considerable quality and volatile variation among cultivars. Eight of 11 cultivars met the standard U.S. No. 1 requirement for °Brix (≥9), and in most cultivars, °Brix declined during fresh-cut storage at 4 °C. Hunter *L** (loss of lightness color value) and *a** (decline of typical orange hue) colors also generally declined during storage in most cultivars. Volatile ester compounds generally decreased during fresh-cut storage or exhibited a transient increase before declining after 5−7 days of storage. The relative percentage of acetate esters declined during storage in all cultivars, and declines were accompanied by simultaneous non-acetate ester increases. Slight imbalances in compound concentrations may alter the overall perception of desirable, typical "cantaloupe" aroma/flavor during fresh-cut storage. Upsetting the unique aroma balance through storage may negatively affect flavor and the consumer's perception of desirable attributes, even though total volatile levels might not decrease substantially until after 5−7 days in storage. Subtle volatile and quality decreases are likely to be exacerbated with immature-harvested cantaloupe and are likely in out-of-season exports that have likewise been harvested at less mature stages. Altogether, this study indicates the difficulty in procuring cantaloupes of consistent quality from local producers, in a given year, for domestically grown fruit.

KEYWORDS: °Brix; cantaloupe; *Cucumis melo*; flavor; fresh-cut; gas chromatography; melon; muskmelon; quality; solid-phase microextraction; soluble solids; volatiles

INTRODUCTION

Fresh-cut processing causes major tissue disruption as vacuolar, cytoplasmic, and nucleic enzymes and substrates mix. Fresh-cut processing increases respiration rates and wound-induced ethylene production and may contribute to flavor and texture change/loss during and after processing (*1*). Because cutting and wounding generally shorten product shelf life, via compromised physiological integrity, changes in quality and flavor need more evaluation. Reports documenting generation and/or loss of flavor and textural quality in cut fruits are emerging (*2*−*11*). Nonetheless, consistent flavor and conservation of postcutting quality in fresh-cut fruits are required to ensure consumer acceptance during the marketability window.

Muskmelons are highly regarded for their unique flavor, and high sugar levels are often the determinant of quality (*12*, *13*). However, soluble solids (SS) in five cantaloupe cultivars were only partially correlated with sweetness (*13*, *14*), and high SS alone did not appear to adequately define good melon quality (*14*−*16*). Within a muskmelon fruit, markedly different sugar levels have been reported at different locations from stem to calyx across various tissue types (*17*). Environmental variation, especially water quality and availability (*18*), can alter the expression of traits normally found in a given cultivar. Recently, soluble solids and composite sugar levels in two commercial orange-fleshed cantaloupe cultivars were reported to deviate significantly from the inbred parental lines and to vary significantly over the season (*19*).

A preliminary volatile appraisal of cantaloupe inbreds indicated that fall-grown fruit displayed dissimilar aroma compound trends compared with prime season, spring-grown fruit (*3*). There is also a detrimental tradeoff between firmness and acceptable volatiles and flavor/aroma attributes in fresh-cut fruits (*4*, *5*, *20*−*22*). Such problems are likely exacerbated with out-of-season, imported fruits due to extended shipping that requires fruit to be harvested at even a less mature stage. We have established that harvest maturity significantly affects the level of flavor volatiles extracted in cv. Keitt and Palmer mango (*4*) and cv. Sol Real cantaloupe (*20*, *23*). Subsequently, numerous cantaloupe cultivars were assessed to determine if within-season variation, in and of itself, might limit the ability of producers to deliver consistent, high-quality fresh-cut products.

MATERIALS AND METHODS

Plant Material and Cultural Practices. Cantaloupe (*Cucumis melo* var. reticulatus, Naudin) cultivars (Athena, Gold Rush, Mission, Oro Rico, Sol Dorado, and Sol Real) were grown on raised beds with

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Table 1. Growing Location and Seasonal Harvest Information for Various Cantaloupe Cultivars for Evaluation during Fresh-Cut Storage (4 °C)

cultivar	harvest information[a]		storage days[b]
eastern			
Athena	mid	Aug 6, Lansdale, PN	0, 4, 6, 11*
Athena	late 1	Sept 17, Lansdale, PN	0, 2, 7, 9*
Athena	late 2	Oct 26, Wellington, FL	0, 2, 5,* 7
western			
Sol Dorado	mid 2	Aug 18, Gilroy, CA	0,* 5, 7, 12
Sol Dorado	main	Oct 27, Yuma, AZ	0, 2, 5, 7
Gold Rush	mid 2	Aug 18, Gilroy, CA	0, 5, 7, 12
Mission	mid 2	Aug 18, Gilroy, CA	0, 5, 7, 12
Oro Rico	mid 2	Aug 18, Gilroy, CA	0, 5, 7, 12
Sol Real	mid 1	Aug 6, Gilroy, CA	0, 4, 6, 11
Sol Real	mid 2	Aug 18, Gilroy, CA	0, 5, 7, 12
Sol Real	mid 3	Aug 24, Gilroy, CA	0, 2,* 5, 7, 9*

[a] Season designation (e.g., mid or late) is according to conditions and opinion of local growers within the harvest region. [b] An asterisk next to the number indicates an occurrence of $n = 1$, as opposed to $n = 2$ or 3, for GC-FID samples.

standard cultural practices in commercial fields with furrow irrigation. Ripe fruits were harvested (**Table 1**) at $^3/_4$-slip according to rigorous standards (*20*) where maturity at first or second commercial harvest was carefully evaluated by trained growers/researchers. Harvest criteria used, per cultivar, were ground color change, fruit size, degree of slip, acceptable °Brix (U.S. No. 1 $\geq$ 9 °Brix), and acceptable taste in the production field. Fruits were field hydrocooled in an ice slurry, cooled on harvest date in a forced-air cooler (~5 °C), packed carefully with Styrofoam packaging beads, and overnight freighted to the Southern Regional Research Center (SRRC) for immediate analysis within 2 days after being held at 4 °C.

Fresh-Cut and Sample Preparation. Fruits were inspected carefully for bruising and compression damage and culled if not in optimum condition. Fruits were washed thoroughly in cold running tap water and then sanitized in 100 μL/L bleach utilizing 5.25% NaClO (pH ~6.5) at 4 °C, rinsed in deionized water, and uniformly peeled on a Muro CP-44 melon peeler (Tokyo, Japan). The stem and blossom portions (~2−3 cm) were removed, and mesocarp cubes (roughly 2.5 cm^3) were prepared (*3*). Cubes from numerous fruits (five to six minimum) were randomized per triplicate, per cultivar, and 300 g was placed into each 24-oz (~1 L) low-profile SRW-24-JC Juice Catcher containers [Winkler Forming Inc., Carrollton, TX (now Pactiv, Lake Forest, IL)]. Containers were stored at 4 °C, and fresh-cut cubes were assessed after various days in storage. Sampling days were not uniform throughout the season because optimum maturity fruit ($^3/_4$-slip) were processed upon receipt, and inclement weather (localized flooding or hurricanes) occasionally closed the SRRC laboratories.

Postcutting Quality Assessments. A subjective hedonic quality criterion was developed for fresh-cut cantaloupe, similar to that of ref *4*, to assess specific attributes and overall quality throughout storage (**Table 2**). Odd whole numbers were sound judgments, whereas even numbers were used for borderline decisions. Two to three trained judges independently performed subjective assessments each sampling day, per cultivar, and results were averaged. Color measurements were recorded with a Hunter color meter (DP-9000, Reston, VA) calibrated against both white (93.088, −0.689, and −0.099, for L^*, a^*, and b^*, respectively) and black color tiles. Color readings were taken from cube edges that were sliced cleanly, not the soft, endocarp side adjacent to the seed cavity nor the skin-peeled side, $n = 15-45$ per treatment. °Brix (percent soluble solids) was measured electronically with an Atago PR101 (Tokyo, Japan) in juice extracted from individual cubes, $n = 5-15$ per treatment. The firmness of individual cubes was measured with a hand-held McCormick FT327 (Alphonsine, Italy) with an 8.0 mm probe, again utilizing edges that were sliced cleanly with knives, $n = 5-15$ per treatment. The probe was positioned firmly and cubes pressed uniformly into the probe. Fruit firmness was measured with a 11.3 mm probe, after removal of the rind.

GC Volatile Sample Preparation. Volatile samples were prepared from a representative pool (8−10 cubes) of tissue from replicated storage containers, per treatment. Tissue was rapidly juiced (~15 s) into slurries with a Braun MP80 juicer (Germany), then 7 mL (without foam) was immediately pipetted into 12-mL glass vials containing 2.5 g of NaCl and a magnetic stir bar. Vials were sealed with a steel crimp cap fitted with a black Viton lid and stirred for 12.5 min at 40 °C in a water bath while exposed to a 100 μm, 1 cm PDMS manual SPME fiber. Prior to use, vials, lids, septa, stir bars, and NaCl were baked overnight at 190 °C. SPME fibers were initially conditioned each day by baking them out for 1 h in the GC inlet, held at 250 °C.

GC-FID. Fibers were desorbed in an HP 5890 GC equipped with a 60 m DB-5, 0.25 mm i.d., 0.25-μm column (J&W Scientific, Folsom, CA) and an FID detector. Samples were run with the following conditions: initial temperature, 50 °C for 1 min, purge off, purge on at 1 min and off again at 20 min, ramped at 5 °C/min until 100 °C, then ramped 15 °C/min until 250 °C, and held for 19 min with the injector port at 250 °C and the detector at 280 °C. Data were collected at 4 Hz and analyzed electronically, with manual reintegration and tangent skimming when necessary, and a program was written to extract and post the average peak area of four integrations per second to spreadsheets. GC-FID data were based on $n = 2$ or 3 samples, but occasionally a run was bad (broken fiber or injection problems), and therefore trends should be viewed with caution for those specific compounds on specific days for a given cultivar where $n = 1$ (denoted in **Table 1**).

Twenty-six compounds were positively identified by GC-FID with standards (**Table 3**). These included ethyl propanoate, ethyl 2-methylpropanoate, 2-methylpropyl acetate, methyl 2-methylbutanoate, butyl acetate, ethyl 2-methylbutanoate, pentyl acetate, benzyl acetate, 3-phenylpropyl acetate (Aldrich Chemical Co. Inc., Milwaukee, WI), methyl acetate, ethyl acetate, propyl acetate, 2-methylbutyl acetate, methyl hexanoate, ethyl hexanoate, hexyl acetate, 1-octanol, ethyl heptanoate, ethyl octanoate, octyl acetate, 2-phenylethyl acetate (Sigma Aldrich, St. Louis, MO), methyl butanoate, ethyl butanoate (Ultra Scientific, North Kingstown, RI), and 1-hexanol (Polyscience Corp., Niles, IL). Compounds were also confirmed by comparison of retention times (RTs) to an in-house retention index (RI) with identical replicate slurries via manual SPME fibers run on GC-MS (below).

Twenty-six GC-FID compounds were integrated for each cultivar/day combination. Reagent grade standards ($n = 3$, per concentration) were run for most compounds at 3−5 orders of magnitude after dissolving in deionized water containing a 10% sucrose solution (v/v), in saturated NaCl (2.5 g/7.0 mL of sample). Results were either expressed as total summed peak area or on a relative percentage basis of each compound's integrated area to the total integration of 26 compounds recovered and positively identified within the first 18 min of the GC-FID run. When similar FID responses were attained each day throughout an experiment, compounds were quantified (parts per billion, weight/volume) on the basis of external calibrated standard curves. On the basis of response factor and bracketing standards versus experimental samples, certain standards (pentyl acetate, ethyl propanoate, methyl butanoate, ethyl hexanoate, ethyl butanoate, methyl-2-methylbutanoate, 1-hexanol, methyl hexanoate, ethyl hexanoate, 1-octanol, and phenethyl acetate) were used to generate linear equations for the 26 volatiles quantified, based on proximity via molecular weight and/or ester branching.

GC-MS. SPME fibers were desorbed at 250 °C for 1 min in the injection port of an HP 6890/5973 GC-MS (Hewlett-Packard, Palo Alto, CA) with a DB-5 (cross-linked 5% phenyl methyl silicone, J&W Scientific) column (30 m, 0.25 mm i.d., 25-μm film thickness) for 35-min runs. Fibers remained in the heated injection port for 5 min as a bake-out step. The injection port was operated in splitless mode and subjected to a pressure of 25 psi of ultrahigh-purity He (99.9995%) for the first minute and then set at a constant velocity of 40 cm s^{-1} for the remainder of the GC run. The initial oven temperature was 50 °C, held for 1 min, ramped at 5 °C min^{-1} to 100 °C and then at 10 °C min^{-1} to 250 °C, and held for 9 min. The HP 5973 quadrupole mass spectrometer was operated in the electron ionization mode at 70 eV, at a source temperature of 200 °C and quadrupole at 106 °C, with a continuous scan from m/z 33 to 300. Data were collected with HP ChemStation software and searched against the NIST (v. 1.5) and Wiley (v. 7 NIST98) libraries (Palisade Corp., Newfield, NY). Compounds

Table 2. Subjective Descriptors for Fresh-Cut Cantaloupe

	subjective score^a				
quality attribute	9	7	5^b	3	1
overall color (loss orange)	none, very fresh and "normal" appearing per cultivar	slightly visible loss of typical orange color	visibly more pale colors and slightly pale flesh that the consumer may notice	obvious pale/whitish discoloration	severely pale "washed" looking
edge or tissue damage	none, very fresh and normal appearing; sharp knives used	slightly visible loss of orange color but not actually soggy or watery looking	edges slightly soggy or water-soaked with darker color; likely texture loss	obvious edge damage, like compression bruising; "gooey" appearance	severe edge damage with obvious water-soaking or associated soggy appearance
spoilage	none	minor; perhaps increased spore counts, but only via lab testing	noticeable by trained person but most consumers may not observe	slimy surfaces on some cubes with a slightly "gooey" appearance	obvious mold, or slimy surfaces and "gooey" pieces (bacterial)
aroma/smell	normal, characteristically strong (excellent)	normal to perhaps slightly "off" or "flat"	detectable "off-odor" (i.e., when open package, but dissipates), still edible	off-odors moderate (slightly anaerobic), becoming musty	off-odors strong; product is "fermented-like" (musty/musky)
desiccation	none, very fresh with a wet gleam	slightly visible water loss on edges, noted by trained persons	progressive drying on cube edges, often undetected by consumers	little to no surface gleam, slightly dehydrated surfaces	severe tissue drying, like white blush on sliced carrots

[a] Generally: 9, excellent; 7, very good; 5, limit, good; 3, fair, absolute limit for household use with trimming and/or loss; 1, poor, inedible. [b] Five is the minimum subjective score (limit) for marketing any product.

were confirmed by their library matches, standards, and comparison to an in-house library and RI (*20*, *23*).

Correlative Quality Analysis. Data were analyzed using S-PLUS 2000, Professional Release 1, Mathsoft, Inc. (Seattle, WA), as a randomized complete block design with a two-way treatment structure (4 × 5) with four day levels, 0, 5, 7, and 12; and five cultivars, Gold Rush, Mission, Oro Rico, Sol Dorado, and Sol Real. Treatment combination replications were described above per parameter, where the experimental unit was the individual fruit or Juice Catcher container. Tukey's multiple-comparison procedure was used to conduct mean comparisons. All comparisons were conducted at the 0.05 α level.

RESULTS AND DISCUSSION

During the course of one growing season, six cultivars were independently assessed from five different harvests, and three cultivars were evaluated two or three times (**Table 1**). Direct comparison for most cultivars was not possible because they were harvested either in different locations (eastern versus western United States) or at different times (seasons). Nonetheless, an analysis of cultivar attributes and volatile patterns led to numerous interesting trends.

Postcutting Quality Assessments. *°Brix.* Most cultivars met the standard U.S. No. 1 requirement (≥9 °Brix) for initial °Brix (percent soluble solids) except for the mid season harvest 2 for Gold Rush, Sol Dorado, and Sol Real (**Table 4**). °Brix steadily declined throughout fresh-cut storage at 4 °C in all three harvests in Athena. In some western shipper (WS) cultivars (i.e., Sol Dorado mid 2, Sol Real mid 1, and Oro Rico mid 2), °Brix increased during storage, followed by a decline. Such increases are likely due to slight sample variation arising from subtle °Brix differences in harvest maturity in randomized fruit. Nonetheless, °Brix tended to decrease by the end of fresh-cut storage, and °Brix declined an average of 11.9% (range, 5.7−18.7) in 8 of the 11 trials. This is similar to other results for both eastern and western shipper cantaloupes (*24*, *25*).

Color and Subjective Appraisals. Hunter L^* and a^* colors generally declined during fresh-cut storage in most cultivars tested, in all season/locations (**Table 5**). The most substantial color declines were observed in Sol Real (mid 1) and Athena mid. Decreases in L^* and a^* are associated with tissue darkening (loss of lightness color value) and loss of typical orange/red color hue, respectively, during storage. Oddly, increased L^* values during storage in fresh-cut watermelon were recently reported (*26*). Nonetheless, slight color losses during fresh-cut storage are likely not noticeable to an untrained consumer. Subjective descriptors for fresh-cut cantaloupe were compiled as an overall average of the five attributes, denoted in **Table 2**, per cultivar. Data revealed that most cultivars maintained acceptable quality for at least 6−9 days (**Table 6**). Overall, gradual declines in all attributes were observed (data not shown), unlike fresh-cut mangos, where specific subjective criteria markedly decreased product acceptability (*4*).

GC-FID Data Manipulation and Volatile Standards. Over the course of the season, several manual PDMS SPME fibers were utilized on a given day for the FID and MS runs. Markedly different total area counts (FID) or total ion counts (MS) within duplicates or triplicates were oftentimes observed, likely due to fiber or injection differences. Volatile recovery differences were also noted in standards run under identical conditions with different fibers on the same day. Furthermore, a differential fiber response regarding volatile recovery of different molecular weight standards was observed (data not shown). To correctly quantify volatiles with standards using SPME, the concentration and identity of every component that might displace low molecular weight compounds from the fiber in a sample should be known (*27*, *28*). Considering the above and that volatile recovery is variable over time on a given fiber (*28*), quantification of compounds was generally not considered, with one exception. If volatile trends observed via selected ion abundance (GC-MS) per cultivar were consistent over replicates each day, data were quantified (**Table 7**). Otherwise, relative percentages were generally used to present volatile data and avoid erroneous quantification in this complicated headspace matrix.

GC-FID and GC-MS Volatile Trends. The GC-FID method routinely recovered 7 of the 24 compounds considered to be flavor-important in muskmelons (*20*, *29*). Ethyl octanoate and (*Z*)-3-octenyl acetate had similar GC-FID RTs and identical GC-MS RIs (1194); however, they were easily separated because WS cultivars such as Sol Dorado and Sol Real have ethyl

Table 3. Commonly Recovered (SPME GC-FID and GC-MS) and/or High-Abundance Volatile Compounds in Cantaloupe and Muskmelons, with Associated Aroma/Flavor Attributes According to the Literature

compound[a]	sensory attributes[b]	FID ID[c]	MS RI	refs[d]
methyl acetate	ethereal, sweet	S	559	
ethyl acetate	brandy, ethereal, fruity, pineapple	S	605	*40*, *41*, *42*, *7*, *43*, *44*
propyl acetate	celery, ethereal, fruity, pear, powerful, raspberry	S	707	*41*, *42*, *43*
ethyl propanoate	acid, ethereal, fragrant, fruity, rum, sweet, weak butter	S	708	*20*, *5*, *41*, *42*, *7*
methyl butanoate	apple, ethereal, fruity, sweet,	S	717	*5*, *41*, *42*
ethyl 2-methylpropanoate (ethyl isobutanoate)	citrus, ethereal, fruity, floral, melon-like, sweet	S	751	*29*, *20*, *5*, *41*, *42*, *7*, *43*
2-methylpropyl acetate (isobutyl acetate)	apple, banana, ethereal, floral, fruity, sweet	S[e]	768	*20, 5, 40, 41, 42, 43, 44*
methyl 2-methylbutanoate	apple, artificial strawberry, floral, fruity, medicinal, sweet	S[e]	772	*29, 20, 5, 3, 41, 42*
(Z)-3-hexenal	apple-like, freshly crushed, green, leafy, powerful, strawberry leaf, wine-like	ND	796	
ethyl butanoate	banana, banana-pineapple, candy, diffusive, fragrant, fruity, ethereal, medicinal, sweet, sick, tutti frutti	S	803	*29*, *20*, *5*, *40*, *45*, *41*, *42*, *43*, *44*
butyl acetate	banana, diffusive, ethereal, fruity, pear, pungent, strawberry	S	812	*20*, *5*, *40*, *41*, *42*, *43*, *44*
ethyl 2-methylbutanoate	cantaloupe-like, floral, fruity, green, melon, powerful, pungent, strawberry, sweet	S	846	*29*, *20*, *5*, *3*, *40*, *41*, *42*, *7*, *43*, *44*
(E)-2-hexenal	almond, apple, fatty, fragrant, fruity, green, leafy, plum, sweet, vegetable	V	850	*29*, *20*
1-hexanol	fragrant, green, herbaceous, mild, sweet, woody	S	865	*42*
3-methylbutyl acetate (isoamyl acetate)[f]	banana, fragrant, fruity, pear, sweet	V	876	*29*, *20*, *5*, *42*, *43*, *44*
2-methylbutyl acetate[f]	banana, candy, citrus, ether, floral, fresh, fruity, citrus, peanuts, fresh, vegetable	S	877	*29*, *20*, *5*, *3*, *40*, *41*, *42*, *7*, *43*
pentyl acetate (amyl acetate)	banana, fruity, ethereal, pear	S	912	*42*
methyl hexanoate	ginseng, nutty, spicy, sweet	S	922	*20*, *5*, *7*, *43*
ethyl hexanoate	apple, banana, brandy, floral, fruity, powerful, wine-like	S	999	*29*, *20*, *5*, *40*, *42*, *7*, *44*
(*Z*)-3-hexenyl acetate	diffusive, fruity, green, strong, unripe banana	S	1004	*20*, *5*, *40*, *41*, *42*, *43*, *44*
hexyl acetate	apple, cherry, floral, pear, wine	S	1011	*29*, *20*, *5*, *3*, *40*, *41*, *42*, *7*, *43*, *44*
eucalyptol (1,8-cineole)	camphoraceous, cool, diffusive, fresh, minty	V	1032	*29*, *23*, *42*, *7*
1-octanol	aldehydic, citrus, fatty, floral, green, sharp, waxy	S	1070	*42*, *44*
ethyl (*E*)-4-heptenoate		T	1090	*20*, *5*
ethyl heptanoate	banana, brandy, fruity, green, pineapple, waxy, winey	S	1099	*20*, *5*, *7*, *43*
(Z)-6-nonenal	citrus, cucumber, green, melon-like	V	1101	*29*, *20*, *3*
(E,Z)-2,6-nonadienal	cucumber, fatty, green, guava, melon, sweet, vegetable, violet, waxy	V	1155	*29*, *20*, *45*, *44*
(***E***)**-2-nonenal**	fatty, green, penetrating, waxy, tallowy	V	1162	*29*, *20*, *44*
phenyl methyl acetate (benzyl acetate)	floral, fruity, fresh, pine, sweet	S	1164	*29*, *20*, *5*, *40*, *41*, *42*, *7*, *43*, *44*
(Z)-6-nonenol	cucumber, green, green melon, melon, powerful, pumpkin, sweet, waxy	V	1171	*29*, *20*, *42*
(Z)-6-nonenyl acetate	honeydew melon	ND	ND	
(Z,Z)-3,6-nonadien-1-ol	muskmelon-like, musky	ND	ND	
(Z)-1,5-octadien-3-one	geranium-like	ND	ND	
ethyl octanoate[g]	banana, brandy, floral, fruity, pear, pineapple	S, V	1194	*7*
(*Z*)-3-octenyl acetate[g]		T	1194	*42*
octyl acetate	floral, fruity, herbaceous, jasmine	S	1213	*42*, *7*, *43*, *44*
ethyl 2-phenylacetate	honey, sweet	S	1243	*23*, *5*, *7*, *43*
phenethyl acetate (2-phenylethyl acetate)	citrus, floral, fruity, green, honey, rosy, sweet	S	1255	*20*, *5*, *42*, *7*, *44*
3-phenylpropyl acetate	balsamic, cinnamic, floral, fruity, honey, spicy, sweet	S	1373	*20*, *40*, *7*, *44*

[a] ***Bold italics*** indicate characteristic impact flavor or aroma compounds (CIFAC) in various muskmelons, as reported in the literature. [b] Compound sensory/aroma attributes contained either within references or in FlavorWorks 2.0 (Anaheim Hills, CA). [c] FID ID = flame ionizing detection via SPME GC on a DB-5 column (cross-linked 5% phenyl methyl silicone). S = confirmed with GC-FID standards; T = tentative; V = verified via in-house RI of identical SPME samples run on GC-MS but not separated or integrated via FID; ND = not detected. All compounds with a "V" designation [i.e. (*E*)-2-hexenal, 3-methylbutyl acetate, eucalyptol, (*Z*)-6-nonenal, (*E*)-2-nonenal, (*Z*)-6-nonenol, (*E*,*Z*)-2,6-nonadienal (Aldrich Chemical Co. Inc., Milwaukee, WI), and ethyl octanoate (Sigma Aldrich, St. Louis, MO) were previously identified with standards via SPME GC-MS, according to ref *23*. [d] Only references not given previously in ref *23* are listed. [e] Methyl 2-methylbutanoate coeluted with 2-methylpropyl acetate in FID samples, as detected and verified via GC-MS. Because the 2-methylpropyl acetate levels were consistently substantially higher compared with methyl 2-methylbutanoate, the combined integration was classified as the acetate for integration purposes. [f] GC peaks coeluted but the MS library differentiated two isomers. [g] Although these compounds have the same GC-FID RT, they were readily differentiated because Athena contained (*Z*)-3-octenyl acetate (tentative), whereas western shippers such as Sol Dorado and Sol Real contained octyl acetate, as confirmed by GC-MS.

octanoate, whereas Athena contained (*Z*)-3-octenyl acetate, according to GC-MS confirmation (**Table 3**).

Even though variability in volatile recovery was found with different manual SPME fibers, the data generally presented interesting trends. The aggregate summed averaged peak areas per cultivar indicated that volatiles generally declined during fresh-cut storage or went through a transient increase before declining by the end of storage (**Figure 1**). Volatile increases during storage were also recently reported in fresh-cut honeydew (*8*). In the mid season 2 harvest, four of five cultivars (Oro Rico, Mission, Gold Rush, and Sol Dorado) had transient volatile increases. This, combined with the low °Brix found in Gold

Table 4. °Brix (Percent Soluble Solids) in Stored Fresh-Cut Cantaloupe Cubes Sampled from Numerous Cultivars Grown throughout the Growing Season in Various Eastern and Western (U.S.) Locations

	days stored at 4 °C								
cultivar, season[a]	0	2	4	5	6	7	9	11	12
Athena, mid	11.69 ± 0.24		10.66 ± 0.47		10.88 ± 0.45			9.93 ± 0.27	
Athena, late 1	11.52 ± 0.29	11.21 ± 0.18				11.18 ± 0.24	10.27 ± 0.22		
Athena, late 2	9.53 ± 0.21	8.09 ± 0.24		8.38 ± 0.19		7.80 ± 0.13			
Sol Dorado, mid 2	7.08 ± 0.20			8.60 ± 0.56		7.86 ± 0.66			7.19 ± 0.38
Sol Dorado, main	9.94 ± 0.15	9.18 ± 0.19		9.55 ± 0.22		8.77 ± 0.12			
Sol Real, mid 1	11.91 ± 0.22		12.06 ± 0.34		12.43 ± 0.26			11.23 ± 0.39	
Sol Real, mid 2	8.41 ± 0.21			8.06 ± 0.37		8.08 ± 0.41			7.81 ± 0.24
Sol Real, mid 3	11.25 ± 0.27	11.08 ± 0.03		11.26 ± 0.29		10.97 ± 0.32	11.65 ± 0.27		
Gold Rush, mid 2	8.84 ± 0.37			8.24 ± 0.39		8.48 ± 0.47			7.98 ± 0.28
Mission, mid 2	10.97 ± 0.13			8.94 ± 0.30		9.62 ± 0.27			8.91 ± 0.41
Oro Rico, mid 2	12.04 ± 0.19			12.80 ± 0.41		10.92 ± 0.56			10.86 ± 0.34

[a] Season designations provided in **Table 1**. Blank cells indicate no measurements recorded on that given day. Averages per cultivar/season generally based on $n = 15$ or 30 for day 0 and $n = 10$ or 15 cubes thereafter, ± standard error (SE).

Table 5. Hunter L^* and a^* Color Readings in Stored Fresh-Cut Cantaloupe Cubes Sampled from Numerous Cultivars Grown throughout the Growing Season in Various Eastern and Western (U.S.) Locations

		days stored as fresh-cut cubes at 4 °C								
cultivar (season)	color	0	2	4	5	6	7	9	11	12
Athena (mid)	L^*	65.63		62.80		62.89			61.89	
	a^*	17.85		11.77		11.75			12.54	
Athena (late 1)[a]	L^*	64.08	65.69				65.69	65.05		
	a^*	9.06	9.59				9.59	8.42		
Sol Dorado (mid)	L^*	–[b]			67.20		66.68			64.99
	a^*	–			12.30		11.53			10.20
Sol Dorado (main)	L^*	64.85	62.41		62.48		–			
	a^*	14.08	13.59		12.49		–			
Sol Real (mid 1)	L^*	66.54		64.69		63.91			61.24	
	a^*	17.29		13.60		12.44			12.60	
Sol Real (mid 2)	L^*	–			68.52		66.36			66.82
	a^*	–			11.65		11.85			10.23
Sol Real (mid 3)	L^*	65.67	65.56		64.65		65.47	64.90		
	a^*	13.40	12.86		13.13		12.54	12.73		

[a] Athena, late 2, was not reported because inclement weather limited data collection. [b] Missing data (–), whereas blank cells indicate no measurements recorded on that given day.

Table 6. Averaged Subjective Assessments in Stored Fresh-Cut Cantaloupe Cubes Sampled from Numerous Cultivars Grown throughout the Growing Season in Various Eastern and Western (U.S.) Locations

	days stored as fresh-cut cubes at 4 °C								
cultivar (season)	0	2	4	5	6	7	9	11	12
Athena (mid)	8.8		8.6		7.0			*5.0*[a]	
Athena (late 1)[b]	9.0	9.0				7.0	*5.0*		
Sol Dorado (mid)	9.0			9.0		8.6			*2.6*
Sol Dorado (main)	9.0	9.0		–[c]		–			
Sol Real (mid 1)	9.0		9.0		9.0			*6.2*	
Sol Real (mid 2)	9.0			8.6		8.6			*4.2*
Sol Real (mid 3)	9.0	9.0		8.4		6.7	6.8		

[a] Italic type indicates product was unmarketable, scoring 5 or below, according to **Table 2**. [b] Athena, late 2, was not reported because inclement weather limited data collection. [c] Missing data (–), whereas blank cells indicate no measurements recorded on that given day.

Rush, Sol Dorado, and Sol Real (**Table 4**), might indicate that this harvest was indeed slightly immature compared with the other cultivars and normal commercial practices. Because fruit-ripening specific and ethylene-regulated genes belong to a large acyl-transferase multifunctional gene family that is increasingly expressed in fruit in early and mid phases of ripening (*30*), discrete classification of ripeness via respiration and ethylene would have been beneficial. In general, cultivars with the lowest total volatile level on day 0 experienced the most dramatic transient increases before volatile levels tapered off (**Figure 1**). Ethylene production is required in apples for continued volatile synthesis (*31*) and, subsequently, volatiles likely increased as fruits finished out their climacteric and associated ethylene burst after cutting. Yet, regardless of initial volatile level, total volatiles generally declined in fresh-cut cubes after 5−7 days of storage.

The same general volatile trends were also observed in Athena and Sol Real with quantified data (**Table 7**). Numerous compounds display a transient increase followed by a precipitous decline by day 11. In Sol Real, acetate and non-acetate esters display this trend; however, many acetates in Athena constantly decline throughout storage. Nonetheless, if data were calculated on a relative percentage basis, most acetates (except low molecular weight compounds) declined constantly through storage, and many higher molecular weight non-acetate esters increased through storage (recalculated data not displayed). An identical pattern has recently been reported in stored fresh-cut Sol Real cantaloupe prepared with five different harvest maturities (*20*).

It has been reported that esters significantly declined by 60% in stored (4 °C) thinly cut cantaloupe after 1 day of storage (*7*, *32*), even though esterase and pectin methyl esterase declined substantially immediately after processing (*33*). In numerous cantaloupe cultivars reported herein, and numerous other melon

Table 7. Quantification (Parts per Billion, Weight/Volume) of Volatiles via Calibrated and Bracketed External Standards Recovered by SPME GC-FID in Fresh-Cut Cantaloupes Stored at 4 °C

	Athena stored for				Sol Real, stored for			
compound	0 days	4 days	6 days	11 days	0 days	4 days	6 days	11 days
methyl acetate	7.7	71.7	12.6	55.1	11.3	6.2	11.8	21.5
ethyl acetate	282.3	280.6	222.1	87.0	128.3	182.1	216.4	149.4
ethyl propanoate	5.3	7.7	13.4	2.4	0.8	13.2	9.7	bt[a]
propyl acetate	32.9	53.4	34.7	9.2	26.6	49.2	40.4	13.4
methyl butanoate	30.2	46.0	31.1	3.0	28.4	125.5	141.1	25.2
ethyl 2-methylpropanoate	6.0	8.0	5.0	bt	7.9	19.6	14.5	bt
2-methylpropyl acetate	367.8	244.0	189.2	57.7	180.1	223.6	158.2	31.6
ethyl butanoate	462.7	890.0	772.9	306.5	682.6	1072.8	1025.1	270.4
butyl acetate	205.3	195.7	169.5	29.8	74.6	101.0	70.2	8.6
ethyl 2-methylbutanoate	47.9	80.2	75.5	11.2	204.5	438.5	353.3	72.1
1-hexanol	72.8	99.8	67.5	32.3	80.6	38.4	48.7	17.5
2-methylbutyl acetate	631.2	473.1	395.3	40.2	414.2	608.3	431.0	1.6
pentyl acetate	19.5	18.8	21.6	4.3	9.5	14.0	10.1	0.6
methyl hexanoate	2.6	3.6	4.4	1.2	2.3	33.3	22.9	11.3
ethyl hexanoate	28.1	77.0	68.4	20.1	142.0	268.3	250.8	93.4
3-hexenyl acetate	164.1	128.6	131.8	57.2	29.1	25.3	18.1	8.2
hexyl acetate	275.8	241.1	269.7	113.9	140.9	247.1	204.1	36.9
1-octanol	8.7	5.0	4.0	2.4	2.6	1.0	1.2	1.7
ethyl (*E*)-4-heptenoate	bt	bt	0.5	bt	0	0	0.1	bt
ethyl heptanoate	0	2.4	2.1	1.3	2.0	9.8	8.7	4.7
benzyl acetate	90.7	69.2	60.4	15.2	115.9	59.9	68.8	28.0
(*Z*)-3-octenyl acetate[b]	0.3	0.6	6.0	0	1.2	1.2	bt	6.5
octyl acetate	77.4	24.9	27.9	8.6	11.6	8.4	0.3	0.4
ethylphenyl acetate	0.2	0.2	bt	bt	2.9	0.6	0.8	0.4
phenethyl acetate	6.2	4.3	2.3	bt	12.7	4.3	8.7	bt
3-phenylpropyl acetate	7.2	10.3	bt	bt	4.3	bt	bt	bt
sum	2833.0	3036.1	2587.8	858.5	2316.8	3551.6	3115.2	803.3

[a] bt = below threshold. Detected but below concentration range per standard equation calibration and calculation. [b] Although this compound was not run as a GC-FID standard, we confirmed herein (GC-MS) and previously (*23*) that it is contained in only Athena. Ethyl octanoate (confirmed by standard), with the identical RT, is found in WS fruit, like Sol Real.

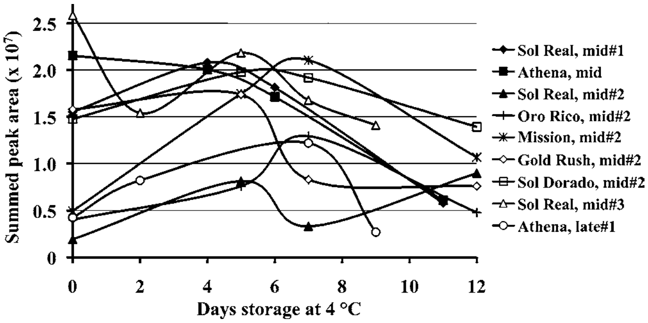

Figure 1. SPME, GC-FID aggregate integrated peak area for 26 volatile compounds in fresh-cut cantaloupe cubes, from several harvests over one season, stored in Juice Catcher containers (4 °C).

cultivars reported elsewhere (*3*, *5*, *6*, *20*, *29*), dramatic short-term ester or aroma losses were not observed. Furthermore, similar short-term volatile losses were generally not reported in stored fresh-cut apple (*34*), honeydew (*8*), mango (*4*), or pineapple (*35*).

Acetate and Non-Acetate Esters. As previously reported in whole fruit (*23*) and stored fresh-cut cantaloupe (*29*), fresh-cut Athena, an eastern U.S. melon with "European" parental lineage, had a much greater proportion of acetate esters (90.4%) compared with the WS Sol Real, 74.5% (data not shown). However, some WS cultivars have comparable levels of acetates (**Figure 2**), as well as honeydews (*29*). In the midseason trial with five WS cultivars, acetates declined during storage in all cultivars, and the declines were accompanied by an almost equal (relative percent) simultaneous non-acetate ester increase (**Figure 2**). This pattern of acetate loss accompanied by non-acetate ester increases was recently reported in numerous cantaloupe and honeydew melons (*29*). Taking into consideration the varied sensory attributes in volatile muskmelon compounds (**Table 3**), it can be surmised that slight changes in compound concentrations may alter the overall perception of aroma/flavor. For example, decreases in certain acetates considered to be "characteristic impact flavor or aroma compounds (CIFAC)" could lessen aroma notes such as apple, banana, cherry, citrus, fragrant, floral, fruity, honey, pear, rosy, and sweet. On the other hand, relative increases in certain non-acetate esters could increase notes such as artificial strawberry, ethereal, green, medicinal, powerful, and pungent. Aldehyde reduction has been found to be ethylene-dependent event in Charentais melons (*36*). The reduction of aldehydes (via alcohol dehydrogenase) into branched-chain alcohols is necessary to produce branched-chain acetates through a condensation reaction with various acetyl moieties,

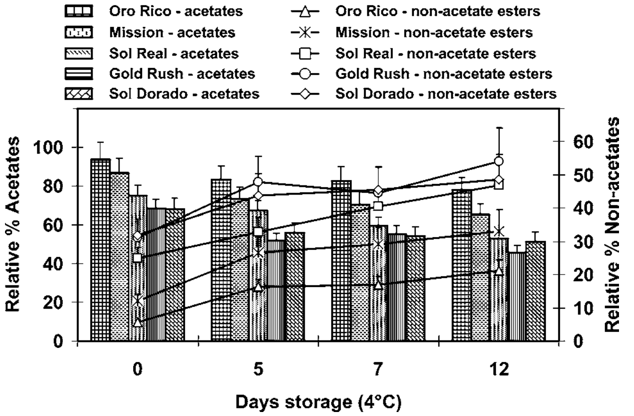

Figure 2. Relative percentage (of 26 integrated compounds) of acetate and non-acetate esters recovered by SPME, GC-FID in numerous mid-season cantaloupe cultivars harvested in one location, fresh-cut, and stored in Juice Catcher containers (4 °C).

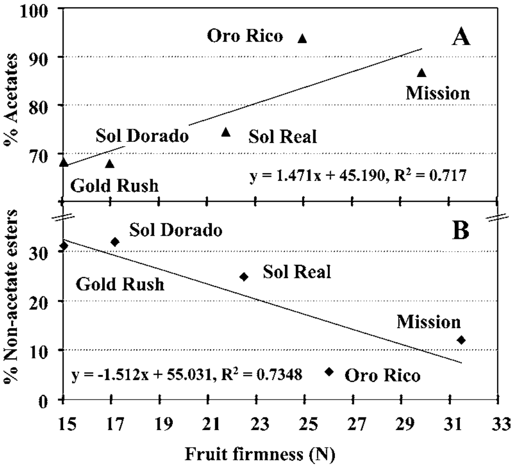

Figure 3. Correlation (α 0.05 level) between whole fruit firmness and volatile esters in five cantaloupe cultivars from a single growing field. Data points represent the average of $n = 4$–6 firmness readings compared with the summed volatiles from $n = 2$ GC-MS runs per cultivar.

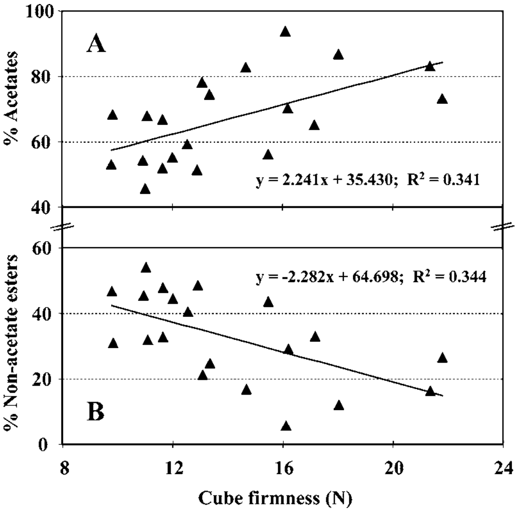

Figure 4. Correlation (α 0.05 level) between fresh-cut cube firmness and volatile esters in five cantaloupe cultivars from a single growing field. Data points represent a two-way treatment structure (D × C = 20) with four day levels (0, 5, 7, and 12) and five cultivars (Gold Rush, Mission, Oro Rico, Sol Dorado, and Sol Real), which are composed of $n = 5$–15 firmness readings compared with the summed volatiles from $n = 2$ GC-MS runs.

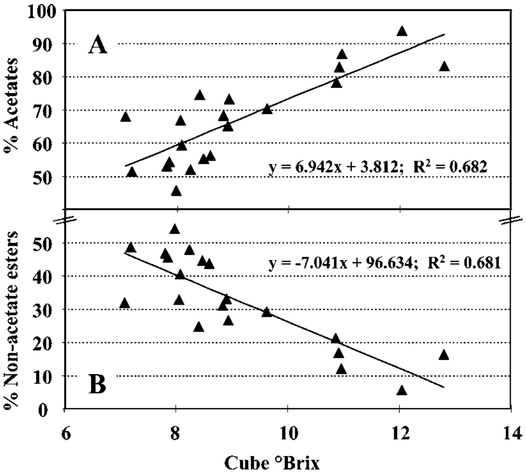

Figure 5. Correlation (α 0.05 level) between fresh-cut cube °Brix and volatile esters in five cantaloupe cultivars from a single growing field. Data points represent a two-way treatment structure (D × C = 20) with four day levels (0, 5, 7, and 12) and five cultivars (Gold Rush, Mission, Oro Rico, Sol Dorado, and Sol Real), which are composed of $n = 5$–15 °Brix readings compared with the summed volatiles from $n = 2$ GC-MS runs.

utilizing alcohol acetyltransferase (AAT) (*30*). A shift in flavor balance during storage appears to be plausible because fresh-cut Sol Real cantaloupes have been shown to have decreased relative percentages of 2-methylbutyl acetate, hexyl acetate, benzyl acetate, 2-methylpropyl acetate, ethyl 2-phenylacetate, and 2-phenylethyl acetate and increased ethyl butanoate, ethyl 2-methylbutanoate, ethyl hexanoate, ethyl propanoate, ethyl 2-methylpropanoate, methyl 2-methylbutanoate, and methyl hexanoate during storage (*29*), almost identical to trends observed in Sol Real and Athena (**Table 7**).

Correlative Analysis of Fresh-Cut Quality. Whole fruit firmness (day 0) was significantly correlated ($\alpha \leq 0.05$) with the level of non-acetate esters and acetates, in a linear manner. Increasing percentage of acetate compounds was positively correlated ($\alpha \leq 0.05$, $r = 0.85$) with fruit firmness (newtons), in the order Mission > Oro Rico > Sol Real > Sol Dorado > Gold Rush (**Figure 3A**). On the other hand, a decreasing percentage of non-acetate esters was negatively correlated ($r = -0.86$) with fruit firmness, with a decent linear relationship whereby Gold Rush < Sol Dorado < Sol Real < Oro Rico < Mission (**Figure 3B**). For the five WS cultivars tested from the same harvest location, this indicates that firmer fruits have higher relative percentages of acetate esters and lower levels of non-acetate esters. The above relationship between acetates and non-acetate esters and firmness was also observed during storage of fresh-cut cubes through 12 days at 4 °C. Acetates were significantly positively correlated ($\alpha \leq 0.05$, $r = 0.58$) with cube firmness (**Figure 4A**), whereas non-acetate compounds were negatively correlated with less firm cubes ($r = -0.58$), in a linear manner (**Figure 4B**).

Likewise, of importance, °Brix of stored fresh-cut cubes was found to be highly correlated ($\alpha \leq 0.05$) with acetates and non-acetate esters during storage (4 °C). Acetates were significantly positively correlated ($\alpha \leq 0.05$, $r = 0.82$) with cube °Brix, whereas non-acetate compounds were negatively correlated ($r = -0.82$) with cube °Brix (**Figure 5**).

Relationships between firmness, sugars, and acetates may be of great interest in similar breeding lines, such as traditional WS cantaloupes, if conserved in more fresh-cut cultivars tested. If firmer tissue is correlated positively with the relative percentage of acetate esters, then it follows that senescing fresh-cut cubes rapidly lose acetates as firmness and ethylene production decline during storage. Significant maturity-independent declines in tissue firmness (*5*) and acetates (*20*, *29*) have been observed in separate experiments with fresh-cut Sol Real cubes. These relationships might be valid but, if and only if, a comparison is made with similar cultivars, grown in the same field.

Flavor and aroma volatiles generally decreased during fresh-cut storage at 4 °C or exhibited a transient increase before gradually declining after 5−7 days of storage. The relative percentage of acetate esters generally declined during storage in all cultivars, and declines were accompanied by an almost equal simultaneous non-acetate ester increase. Theoretically, upon breakdown, the acetate-associated backbones (i.e., 2-methylpropanoic acid, 2-methylbutanoic acid, and hexanoic acid) react with available alcohols (mainly methanol and ethanol) in the presence of AAT to synthesize additional non-acetate esters (e.g., ethyl 2-methylpropanoate, methyl 2-methylbutanoate, and ethyl hexanoate). It is therefore inferred that slight imbalances in compound concentrations in the overall melon volatile profile may alter the overall perception of desirable, typical “cantaloupe” aroma/flavor. Subsequently, upsetting the unique CIFAC balance through storage may negatively affect flavor and the consumer’s perception of desirable attributes, even though the total concentration of volatiles might not decrease substantially until after 5−7 days in storage.

In WS cultivars harvested from the same field, whole fruit firmness and both cube firmness and °Brix during fresh-cut storage were significantly correlated with the relative levels of acetate and non-acetate esters. Herein, and in another 2-year repeated study with Sol Real (*5*), fresh-cut cubes rapidly lost firmness as acetate levels concomitantly declined during storage (*20*). Tissue firmness is correlated positively with higher relative percentages of acetates. Acetate ester levels increase with the ripening of the fruit (*23*) and then decrease as the fruits progress to the over-ripe stage (*37*). A possible explanation is given by the decomposition of pyruvate (*38*) into ethyl esters and acetate esters. Once the pyruvate pool has metabolized, the formation of acetate esters stops as there is no longer starting material (acetyl-CoA), or creation of ethylene-dependent branched-chain alcohol moieties required for the formation of additional acetates, and their concentration falls off as they are catabolized. Yet, degradation products can re-enter the acyl substrate pool, as backbones, to create new non-acetate esters (*29*, *39*). If this relationship is ubiquitous for melons, marked acetate decreases during storage should always correlate with firmness loss. Apparent ester recycling is therefore likely coupled with enzyme activities (e.g., lipase, esterases, pectin methyl esterase, and polygalacturonase) that demobilize cell walls during senescence. Subsequently, acetate levels could be used as a marker for optimum quality and to predict overall volatile and texture loss in stored fresh-cut cantaloupe.

ABBREVIATIONS USED

AAT, alcohol acetyltransferase; CIFAC, characteristic impact flavor or aroma compound; GC, gas chromatograph; MS, mass spectrometer; PDMS, polydimethylsiloxane; SPME, solid-phase microextraction; RI, retention index; RT, retention time; WS, western shipper.

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