JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

Correlating Volatile Compounds, Sensory Attributes, and Quality Parameters in Stored Fresh-Cut Cantaloupe

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Changes in post-cutting volatiles, quality, and sensory attributes during fresh-cut storage (4 °C) of cantaloupe (*Cucumis melo* L. var. Reticulatus, Naudin, cv. 'Sol Real') harvested at four distinct maturities (1/4-, 1/2-, 3/4-, and full-slip) were investigated after 0, 2, 5, 7, 9, 12, and 14 days in a 2-year study. Increased fruity and sweet taste attributes were negatively correlated with percent acetates, aromatic acetates, and total aromatic compounds, and positively correlated with percentage non-acetate esters. Ethyl hexanoate was strongly positively correlated with fruity and sweet taste. Cucurbit, water-like, hardness, cohesiveness, and denseness were positively correlated with percentage acetates, aromatic acetates, and total aromatic compounds, and negatively correlated with percentage non-acetate esters. Several non-acetate esters such as ethyl 2-methyl propanoate, ethyl butanoate, ethyl 2-methyl butanoate, and ethyl hexanoate were negatively (often strongly) correlated with cucurbit. Hardness was positively and strongly correlated with aromatic acetates and all aromatic (benzyl) compounds. In summary, firmer and denser cubes contained more acetates and fewer non-acetate esters. The apparently negative or undesirable attributes cucurbit and water-like were associated with higher acetates and aromatic compounds. Overall, relatively strong (year × maturity × day) correlations among numerous physiological, volatile, and sensory measures were found in this study. Highly significant (stronger) correlations were found in a year × day analysis used to pair maturity means; however, year and interaction effects require prudence when interpreting that data. Nonetheless, both analyses delivered almost identical trends, and strong correlations occurred even though samples were randomized from numerous fruits, per maturity, per juice catcher container, over 2 years. Further interpretation and biochemical explanation are needed to rationalize why mainly only non-acetate esters were highly correlated with desirable sensory and quality parameters.

KEYWORDS: Acetate; aldehyde; aroma; correlation; *Cucumis melo*; ester; flavor; fruit; maturity; melon; minimal processing

INTRODUCTION

Fresh-cut produce is the fastest growing food category in U.S. supermarkets. Total fresh-cut sales (food service plus retail) was expected to be $14 billion in 2005, and fresh-cut fruit sales are expected to top $1 billion per year by 2008 (*1*). Recently, retail scan data from August 2002–2003 (Information Resources Inc.) indicated that fresh-cut fruit sales hit $243 million, an impressive 15 percent increase in one year (*2*). Sales trends for fresh-cut salads indicate clearly that consumers will pay for the convenience of fresh-cut, if quality is perceived to be better than or equal to uncut product. However, fresh-cut fruit sales have lagged behind their counterpart, vegetables, due to numerous physiological and biochemical phenomena. Melons and fresh-cut melons are rapidly gaining a large share of the produce market (*3*), and therefore, a substantial monetary incentive exists to improve their intrinsic qualities. Consumers often buy the first time based on appearance, but repeat purchases are driven by expected quality factors such as flavor and texture (*4, 5*).

Since a firm product is desired for improved shipping, handling, and storability, fruit destined for cutting might be harvested or cut when less ripe. However, there appears to be a detrimental trade-off between firmness and acceptable volatiles and flavor/aroma attributes in fresh-cut fruits (*6–8*). We have established that harvest maturity significantly affects the level

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10.1021/jf070282n CCC: $37.00
Published on Web 10/19/2007

of flavor volatiles extracted from 'Athena' and 'Sol Real' cantaloupe (*4*, *9*), similar to results found in 'Makdimon' melons harvested 2 days before full-slip (FS), when fully ripe (*10*). We have demonstrated that cantaloupe fruit harvested at different maturity delivered stored cubes differing significantly in quality (*11*) and flavor and textural attributes (*4*, *8*). In general, cubes prepared from ≥1/2-slip fruit had excellent sensory attributes, texture, and quality compared against less ripe and FS cubes (*8*, *11*). Volatile compounds followed highly linear trends by which increasing maturity was associated with increased total compounds, total esters, non-acetate esters, aromatic (benzyl) compounds, and sulfur compounds, and decreasing levels of acetates and aldehydes (*4*). Maturity-associated trends were generally conserved through fresh-cut storage.

Although increasing fruit maturity is known to be responsible for improved organoleptic qualities according to most consumers, a comprehensive appraisal of quality during storage in fresh-cut fruits prepared at various maturities is lacking. Maturity-independent changes were observed in the acetate/non-acetate volatile compound ratios during fresh-cut storage (*4*). We believe no successful attempts have been made to statistically correlate volatile, sensory, and postharvest quality attributes in stored fresh-cut fruits prepared from fruit with discrete harvest maturity categories. Although post-cutting quality (*11*), sensory evaluation (*8*), and volatiles (*4*) have been reported in fresh-cut cantaloupe prepared from various maturity stages, no articles were found correlating a myriad of quality parameters with post-cutting shelf-life and sensory quality in cantaloupe. Subsequently, in lieu of performing a quantitative descriptive analysis augmented via consumer testing to determine threshold concentrations of potential characteristic impact flavor or aroma compounds (CIFAC) or like/dislike attributes, we conducted analyses of variance (year × maturity × day, and year × day means), generated correlation coefficients, and visualized the correlation using *h*-plots (*12*).

MATERIALS AND METHODS

Anthesis Tagged Cantaloupe Harvest. Orange-flesh cantaloupes (*Cucumis melo* var. Reticulatus, Naudin, cv. 'Sol Real') were grown in Kettleman City (year 1) and Five Points (year 2), CA, as previously described (*4*). Briefly, 4000–6000 flowers were tagged during anthesis in one morning during peak flowering, and developing fruit proximal to tagged flowers were removed. Fruit were harvested 38 DAA in year 1 at 1/4-, 1/2-, 3/4-slip, and FS, and in year 2 at 37 DAA. Increasing slip designation indicates a progressive physiological increase in maturity, along with associated organoleptic properties, as previously described (*11*). Fruit were field hydrocooled, stored 2 days at ∼5 °C, packaged in Styrofoam beads, and freighted overnight to the Southern Regional Research Center, New Orleans, LA, laboratory for analysis. In year 1, five days elapsed between harvesting and fresh cutting, and 4 days elapsed before cutting in year 2.

Fresh-Cut Cube Preparation. Optimum fruit (no bruising and compression damage) were washed in cold running tap water then sanitized in 100 μL L^{-1} bleach (5.25% NaClO, pH ∼6.7), rinsed in deionized water, peeled using a Muro CP-44 Melon Peeler (Tokyo, Japan), and sliced into 2 to 3 cm × 2.5 × 2.5 cm cubes in pie-like wedges. Processing was done under strict sanitary conditions, employing good manufacturing practices in a stainless steel food preparation kitchen. Cubes from numerous fruits (5–6, per maturity, minimum), were randomized and roughly 300 g were placed into 24-ounce (∼710 mL) low profile SRW-24-JC Juice Catcher containers (Pactiv Corp., Lake Forest, IL) and stored at 4 °C. Cubes were assessed from individual containers (container = experimental unit, EU) after a 0, 2, 5, 7, 9, 12, and 14 day storage. After observing little to no fungal or bacterial decay after a 9 day storage in the first year, the fresh-cut shelf-life was extended in year 2 to 14 day.

Subjective Appraisals. A complete and uniform subjective quality criterion was utilized, as previously described (*13*). Overall color, edge or tissue damage, spoilage, aroma/smell, and desiccation were evaluated on a 1–9 scale where 9 = excellent (just cut, typical of the cultivar); 7 = very good; 5 = good, limit for marketing; 3 = fair, absolute limit for household use with trimming and/or loss; 1 = poor, inedible. Three trained judges independently performed subjective assessments each sampling day, and results were averaged.

Quality Measurements. Soluble solids (%Brix) were measured from extracted juice samples or expressed cubes with a hand-held electronic refractometer (Atago, PR101, Tokyo, Japan). %Brix and pH were measured from homogenized samples prepared for volatile analysis, described below. On each day, 10 fresh-cut cubes, per maturity, were selected and carefully trimmed on each side to 1 cm with two razor blades mounted in a stainless steel device. A compression test to 75% of original size was performed in 1 cm^3 cubes on a Texture Technologies, Stable Micro System Texture analyzer TA.XT2 (Scarsdale, NY), as previously described (*8*). Cubes were compressed with the original rind-side down since specimen orientation significantly affects resultant mechanical textural properties in apples (*14*). Instrumental texture measures reported were force (N) at the bioyield point, bioyield area (Ns), slope of the force deformation curve (N s^{-1}) until the first inflection point, which indicates the point of nondestructive elastic deformation, total force (Ns) area (TA) under the curve and Young's modulus (MPa). Firmness was also measured manually in individual cubes with a hand-held penetrometer (McCormick, FT327, Alphonsine, Italy) with an 8 mm probe. Color (L^*, a^*, and b^*) was recorded with a Hunter color meter (DP-9000, Reston, VA) calibrated against both white and black tiles. Four color measurements were taken per cube from five cubes per triplicate EU per fresh-cut treatment combination, $n = 120$. All penetrometer and color readings were taken from the sides of each cube that were sliced with a sharp knife, not the soft internal cavity-side or the external peeled side.

Headspace GC-MS Solid Phase Microextraction (SPME). Volatile samples were prepared in triplicate, each from 300 g of randomized fresh-cut cubes from a minimum of five fruit per maturity, as previously described (*4*, *9*). Briefly, tissue was rapidly juiced (∼15 s) into a slurry with a Braun MP80 Juicer (Germany), a 3-mL slurry was immediately pipetted into 10-mL glass vials containing 1.1 g of NaCl, and then a 2-methylbutyl 3-methylbutanoate internal standard (IS) was added (10 μg kg^{-1}, final concentration). Vials were sealed with a steel crimp cap fitted with a Teflon/silicon septum, and placed on a Combi-Pal Autosampler (Leap Technologies, Carrboro, NC) cooling rack at 4 °C. Vials were equilibrated 10 min via oscillation (100 rpm) in a 40 °C autosampler, then a 1-cm 100 μm polydimethylsiloxane (PDMS) SPME fiber extracted the headspace for 12.5 min at 40 °C (close to the temperature of the human palate, where mastication occurs). Fibers were desorbed at 250 °C for 1 min in the injection port of an HP6890/5973 GC-MS (Agilent Technologies, Wilmington, DE) with a DB-5 (cross-linked 5% phenyl methyl silicone, J&W Scientific, Folsom, CA) column (30 m, 0.25 mm i.d., 25 μm film thickness) for 30 min runs. The injection port was operated in splitless mode and subjected to a pressure of 173 kPa of ultrahigh purity helium (99.9995%) for the first minute, and then flow velocity was constant at 40 cm s^{-1} for the remainder of the GC run. The initial oven temperature was 50 °C, held 1 min, ramped 5 °C min^{-1} to 100 °C, then 10 °C min^{-1} to 250 °C and held 9 min. The HP5973 quadrupole mass spectrometer was operated in the electron ionization mode at 70 eV (electron volts), a source temperature of 200 °C, with a continuous scan from *m*/*z* (mass to charge ratio) 33 to 300. Year 2 GC-MS conditions were identical to year 1, except that cryofocusing (−60 °C) at the GC inlet was utilized as compounds were desorbed (1 min) from the SPME fiber atop the column.

GC-MS Data Analysis. Data were collected with HP ChemStation (Agilent Technolgoies, Wilmington, DE) software (A.03.00) and searched against the Wiley registry of mass spectral data (seventh edition, Palisade Corp., Newfield, NY). Aside from one unknown acetate, most compounds were confirmed by standard comparisons, MS ion spectra, and an in-house retention index (RI) (*9*) according to **Table 1**. The retention time from a series of straight-chain alkanes (C_7–C_{20}), produced on the aforementioned column under identical conditions,

Table 1. Volatile and Semi-Volatile Compounds Recovered in Fresh-Cut Cantaloupe Juice Samples via Solid Phase Microextraction, Gas Chromatography–Mass Spectrometry (SPME GC-MS)

compound class	RI[b]			
compound[a]	(DB-5)[c]	CAS No.	ID[d]	source[e]
non-acetate esters				
methyl 2-methylpropanoate	690	547-63-7	S	S
ethyl propanoate	708	105-37-3	S	A
ethyl 2-methylpropanoate	*751*	*97-62-1*	*S*	*A*
methyl 2-methylbutanoate	*772*	*868-57-5*	*S*	*A*
ethyl butanoate	*803*	*105-54-4*	*S*	*A, U*
ethyl 2-methylbutanoate	*846*	*7452-79-1*	*S*	*A*
ethyl pentanoate	900	539-82-2	S	*A*
methyl hexanoate	922	106-70-7	S	A, U
butyl butanoate	994	109-21-7	S	A
ethyl hexanoate	*999*	*123-66-0*	*S*	*A, S, U*
methyl heptanoate	1021	106-73-0	S	U
2-methyl butylbutanoate	1056	51115-64-1	MS, T	
ethyl (*E*)-4-heptenoate	1090	54340-700-4	MS, T	
propyl hexanoate	1094	626-77-7	S	S
ethyl heptanoate	1099	106-30-9	S	A, S
2-methylbutyl isovalerate	1107	2445-77-4	IS	A (IS)
3-methylbutyl hexanoate	1254	2198-61-0	S	A
pentyl hexanoate	1282	540-07-8	S	A, S
acetates				
2-methylpropyl acetate	768	110-19-0	S	A
butyl acetate	812	123-86-4	S	J
3-methylbutyl acetate	*876*	*123-92-2*	*S*	*A*
2-methylbutyl acetate	*877*	*624-41-9*	*S*	*A, S*
unknown alkyl acetate	975			
(*Z*)-3-hexenyl acetate	1004	3681-71-8	S	S
hexyl acetate	*1011*	*142-92-7*	*S*	*A*
(*E*)-3-hexenyl acetate	1018	33467-73-1	S	S
benzyl acetate	*1164*	*140-11-4*	*S*	*A*
phenylethyl acetate	1243	101-97-3	S	S
ethyl phenylacetate	1255	103-45-7	S	A
alcohols				
2-methyl 1-butanol	733	137–32–6	S	A, P
eucalyptol	*1032*	*470-82-6*	*S*	*A*
benzyl alcohol	1033	100-51-6	S	P
phenyl ethyl alcohol	1113	60-12-8	S	A, U
(Z)-6-nonenol	*1171*	*35854-86-5*	*S*	*A, B*
nonanol	1172	143-08-8	S	A
benzenepropanol	1232	122-97-4	S	U
aldehydes				
hexanal	801	66-25-1	S	A, U
(E)-2-hexenal	*850*	*6728-26-3*	*S*	*A*
benzaldehyde	962	100-52-7	S	A
octanal	1003	124-13-0	S	A, U
benzeneacetaldehyde	1043	122-78-1	S	A
(E)-2-octenal	*1057*	*2548-87-0*	*S*	*A*
(Z)-6-nonenal	*1101*	*2277-19-2*	*S*	*A*
nonanal	1104	124-19-6	S	B, S
(E,Z)-2,6-nonadienal	*1155*	*557-48-2*	*S*	*A*
(E)-2-nonenal	*1162*	*18829-56-6*	*S*	*A*
(*E,Z*)-2,4-nonadienal [f]	1196	2363-88-4	MS	
(*E,E*)-2,4-nonadienal	1216	5910-87-2	S	A
(*Z*)-citral [g]	1240	106-26-3	S	A
(*E*)-citral [g]	1270	141-27-5	S	A
(*E*)-2-undecanal	1306	112-44-7	S	A
sulfur compounds				
S-methyl 3-methylbutanethioate	938	23747-45-7	MS, T	
ethyl 2-(methylthio)acetate	*981*	*4455-13-4*	*S*	*A*
methyl 3-(methylthio)propanoate	1023	13532-18-8	S	A
ethyl 3-(methylthio)propanoate	*1098*	*13327-56-5*	*S*	*A*
3-(methylthio)propyl acetate	1123		MS, T	

[a] Characteristic impact flavor and aroma compounds (CIFAC) are italicized, as reported in the *Cucumis melo* literature (*25, 26, 28, 37–41*). [b] RI = retention index, calculated with *n*-alkanes (*9*). [c] DB-5 = cross-linked 5% phenyl methyl silicone column. [d] ID = identifications according to abbreviations where IS = internal standard; MS = mass spectrometry ion comparisons; S = confirmed with standards; T = tentatively identified. [e] Standards acquired from A = Aldrich Chemical Co. Inc., B = Bedoukian Research Inc., F = Fluka, J = JT Baker Chemical Co., P = PolyScience, S = Sigma Aldrich Inc., and U = Ultra Scientific. [f] Isomer deduced via RT and MS based on impurity reported in the (E,E) isomer standard. [g] A mixed cis, trans standard was utilized, and resultant stereoisomers were separated by MS.

were used to calculate RIs for all identified compounds. Spectra were integrated based on qualifying and progeny ions to discriminate and identify compounds compared against standards. Standards were acquired from Aldrich Chemical Co. Inc. (Milwaukee, WI), Bedoukian Research Inc. (Danbury, CT), Fluka (now Sigma-Aldrich) (Buchs, Switzerland), JT Baker Chemical Co. (Phillipsburg, NJ), PolyScience (Niles, IL), Sigma Aldrich Inc. (St. Louis, MO), and Ultra Scientific (North Kingstown, RI), according to **Table 1**. Relative percent recovery was expressed per compound as the target response divided by the total suite of 55 compounds positively identified per sample, in triplicate ($n = 3$), combined over the two years. Volatile classes and selected compounds reported in the literature that are considered CIFAC were analyzed and presented. Compound classes were tallied and comprised acetates, non-acetate esters, total esters, aromatic esters, total aromatic (benzyl-containing) compounds, sulfur compounds, and alcohols, as previously described (*4*), as denoted in **Tables 1** and **2**.

Sensory Evaluation. The spectrum intensity scale for descriptive analysis was followed, with supplemental texture scales developed in-house (*15*). Nine fully trained panelists, who had from one to eight years' experience in descriptive sensory analysis techniques, evaluated cantaloupe samples during both years, as previously reported (*8*), utilizing flavor references as previously described (*15, 16*). Nine flavor, taste, and mouth feel attributes (fruity/melon, FTY; cucurbit, CRB; sweet aromatic, SWA; sweet taste, SWT; musty, MST; rancid, RNC; chemical, CHM; water-like, WTR; and astringent, AST) and five texture attributes (wetness, WET; hardness, HRD; denseness, DEN; cohesiveness, COH; and moisture release, MOI) were rated on a 0 to 15-point anchored intensity scale, with 0 = not detectable and 15 = more intense than most foods (*17*). Sample presentation order was randomized for each session, over both years, and both years of data were combined for statistical analysis.

Statistical Methods. Data were analyzed using SPlus (Release 7.0) as a randomized complete block design with a two-way treatment structure, day with seven levels, 0, 2, 5, 7, 9, 12, and 14; and maturity with four levels, 1/4-slip, 1/2-slip, 3/4-slip, and FS, with the exception of color, and the subjective variable edge or tissue damage. The study was repeated in two years; however, there were no year 1 measurements for days 12 and 14. Each treatment combination had three discrete containers as replications (EU), from which individual cubes comprised subsamples. Six EUs were prepared per treatment combination, per year; however, three were used for sensory appraisal, and three were used for all other measures. The Tukey multiple comparison procedure was employed to evaluate mean differences when main effect or interaction means were statistically significant (p value < 0.05). All multiple comparisons were conducted at the 0.05 level of significance.

There were statistically significant (p value <0.05) day × maturity interaction effects for subjective deterioration, hand-held firmness, aroma/smell, and desiccation and statistically significant (p value <0.05) year effects for Hunter, subjective color data (*11*), and most volatile classes (*4*). Since for most response variables the effect of maturity was dependent on a particular day, correlations were constructed using the maturity × year (M × Y) means for a particular day. Correlation coefficients are reported along with the p value for the test of the null hypothesis; the correlation coefficient is zero.

In year 1, there were 20 observations (days = 0, 2, 5, 7, 9 and maturities = 1/4, 1/2, 3/4, FS), and in year 2, there were 28 observation (days = 0, 2, 5, 7, 9, 12, and 14, and maturities = 1/4, 1/2, 3/4, and FS). The means for the sensory data were taken over panelists, and the means for the physiological and volatile data were taken over EU, and block. Sample size used to calculate the coefficients of correlation was 20 for the physiological texture versus sensory correlations (year 1 measurements only: bioforce, bioarea, slope, TA, and MPa) and 48 for all others except the physiological color measurements. Scatter plots are provided for correlations considered "strong" ($\geq \pm 0.7$, boldfaced in tables). Specific volatile compounds presented in tables include only those that had at least one correlation with one of the physiological or sensory measurements that was considered moderate ($\geq \pm 0.55$, italicized in tables).

Correlation coefficient matrixes were generated, and corresponding variables were visualized using *h*-plots (*12*). The *h*-plot displays the Pearson's product-moment correlation coefficient as the cosine of the

Table 2. Relative Percentage of Characteristic Impact Flavor or Aroma Compounds (CIFAC), Acetates and Non-acetate Esters in Fresh-Cut Cantaloupes Harvested at Various Maturities and Stored up to 14 Days at 4 °C[a]

	days storage at 4 °C ± standard error (SE)						
compound class	0	2	5	7	9	12	14
CIFAC[b]							
full-slip	64.22 ± 0.13	63.45 ± 1.12	65.98 ± 0.70	67.46 ± 0.57	67.68 ± 1.17	72.25 ± 0.31	72.67 ± 0.04
3/4-slip	60.96 ± 0.82	60.28 ± 1.55	62.47 ± 0.71	65.07 ± 0.89	64.89 ± 2.85	71.43 ± 1.03	72.14 ± 0.30
1/2-slip	53.52 ± 0.65	57.90 ± 0.49	59.80 ± 0.10	62.52 ± 1.63	65.78 ± 3.31	72.28 ± 0.09	71.73 ± 0.07
1/4-slip	46.60 ± 1.22	54.59 ± 0.54	57.53 ± 1.72	58.19 ± 2.85	59.85 ± 3.85	68.54 ± 0.12	68.53 ± 0.73
acetates							
full-slip	53.32 ± 1.31	46.81 ± 3.31	34.65 ± 4.42	35.69 ± 3.45	32.82 ± 3.34	23.81 ± 0.53	27.34 ± 1.72
3/4-slip	61.79 ± 1.62	52.26 ± 1.85	41.81 ± 3.90	42.01 ± 5.39	38.02 ± 4.24	25.74 ± 0.05	31.14 ± 0.33
1/2-slip	71.78 ± 2.65	52.69 ± 3.83	41.44 ± 4.58	40.57 ± 6.62	35.80 ± 6.94	22.92 ± 0.75	27.89 ± 0.42
1/4-slip	80.73 ± 0.51	59.04 ± 2.00	44.91 ± 5.55	48.40 ± 7.67	44.19 ± 7.86	32.21 ± 1.02	32.55 ± 0.08
non-acetate esters							
full-slip	43.44 ± 0.88	50.65 ± 3.30	62.34 ± 4.28	61.46 ± 3.34	63.98 ± 3.23	27.34 ± 1.72	70.63 ± 1.63
3/4-slip	34.82 ± 1.81	44.47 ± 1.80	55.12 ± 4.01	55.00 ± 5.32	59.29 ± 4.26	31.14 ± 0.33	67.26 ± 0.31
1/2-slip	21.90 ± 2.97	44.07 ± 4.18	55.65 ± 4.68	56.69 ± 6.73	61.61 ± 6.80	27.89 ± 0.42	70.21 ± 0.34
1/4-slip	10.87 ± 1.43	36.72 ± 2.53	51.50 ± 6.33	47.82 ± 8.14	53.13 ± 7.71	32.55 ± 0.08	65.65 ± 0.07

[a] Year by maturity by day means, Y × M × D. [b] Characteristic impact flavor or aroma compounds (CIFAC) category comprised 19 compounds, as italicized in **Table 1**. Acetates comprised 11 compounds, and non-acetate esters comprised 17 compounds, according to **Table 1**.

angle between the centered variable profiles. Each variable is represented by a radius, where clusters of positively correlated variables correspond to clusters of radii, and groups of clusters separated by 180° are negatively correlated. This is unlike star plots where spoke length conveys meaning regarding the variable's numeric value/weight.

RESULTS AND DISCUSSION

Maturity and Volatiles. The integrated, combined target response for acetates and non-acetate esters increased with harvest maturity, and in a linear manner with increasing maturity, conserved through fresh-cut storage (*4*, *8*). Total target response for most compound classes continuously increased through 7 day fresh-cut storage (*4*). Across maturity, however, there was only a 3.3-fold increase in acetates on day 0 compared with an 18-fold increase in non-acetates (*4*). Subsequently, to express two seasons of SPME volatile data as quantitatively as possible, relative percentages were utilized. Upon cutting (day 0), 11 acetates accounted for the majority (53.3–80.7%) of the total ester abundance at harvest across maturity, whereas the 17 non-acetate esters accounted for less than one half (10.9–43.4%) the total esters (**Table 2**). Acetates have been found to increase markedly with increasing fruit development and maturity in apple (*Malus* × *domestica* Borkh.), cantaloupe, and pear (*Pyrus communis* L.) (*4*, *9*, *18*, *19*). Acetates dominated the volatile profile in Charentais melons, even though three non-acetate esters were recovered in appreciable quantities (*20*). Recently, numerous acetates (isobutyl acetate, 2-methylbutyl acetate, hexyl acetate, (*Z*)-3-hexenyl acetate, and benzyl acetate) were found to be the most abundant esters recovered in cantaloupe and Charentais melons (*21*). Moreover, it has been found that butyl acetate, 2-methylbutyl acetate, and hexyl acetate were the most abundant compounds in Galia-type melons (*22*). Acetates are often considered the most important class of volatiles, imparting to fruits their unique and characteristic aroma and flavor, especially in Galia or Charentais type fruit (*23*, *24*). However, four non-acetate esters, ethyl 2-methylpropanoate (ethyl isobutyrate), methyl 2-methylbutanoate, ethyl butanoate, and ethyl 2-methylbutanoate were found to have the highest odor values by GC-O in Charentais melons (*25*), and aromagram techniques indicated that the primary muskmelon odorants were methyl 2-methylbutanoate, (*Z*)-3-hexenal, (*E*)-2-hexenal, and ethyl 2-methyl propanoate (*26*).

According to the aggregate CIFAC data, there was an increase in maturity, as previously observed with the CIFAC and non-acetate esters. However, this maturity-dependent increase was not consistently conserved through storage (**Table 2**). As previously reported, acetates declined but non-acetates markedly increased, likely due to catabolism of recycled substrate moieties and alcohols (*27*), probably combined with a lack of amino acid or pyruvate-derived acyl backbone substrates. The contribution of CIFAC actually increased through fresh-cut storage (**Table 2**). This illustrates how relative abundance or concentrations reported in the literature may erroneously estimate the importance of volatiles regarding sensory attributes. Apparently CIFAC in the literature are confounded within the melon group, or such high diversity exists that simplifying and categorically stating which compound(s) or compound class(es) is important in *Cucumis melo* is dubious.

More balanced distribution of acetates and non-acetates were present in 3/4-slip and FS fruit, compared with less mature samples (**Table 2**). Eastern-type U.S. cantaloupe fruit (Athena) had more acetates, including unsaturated alkenyls of higher molecular weight, compared with WS cantaloupe ('Sol Real') (*9*, *27*). Similar profiles have been observed in numerous melons, as outlined above. Since there is a uniform change in the ester balance through fresh-cut storage that is independent of initial processing maturity (*4*), actual or relative acetate concentration might not be so important regarding flavor. Subsequently, we reviewed sensory and volatile correlations during fresh-cut storage.

Volatile and Sensory Correlations. Acetates dominated the volatile profiles only during the initial stages of storage (up to 5 days) in 'Sol Real', and for less mature fruit (**Table 2**). Yet, their relative percentages were not so important based on sensory attributes, associated with desirable fruit characteristics. Further details of these correlations can be visualized readily in plots designed to illustrate complex correlation matrices (**Figures 1** and **2**). Although the plots do not implicitly detail coefficients of correlation (similar to **Tables 3** and **4**), one can ascribe relative relationships between parameters closely related, and inversely related (separation close to 180°). Although presented in **Figure 1**, sweet aromatic (SWA), chemical (CHM), wetness (WET), mustiness (MST), and rancid (RNC) attributes exhibited no correlation with any volatile or class of volatile compounds,

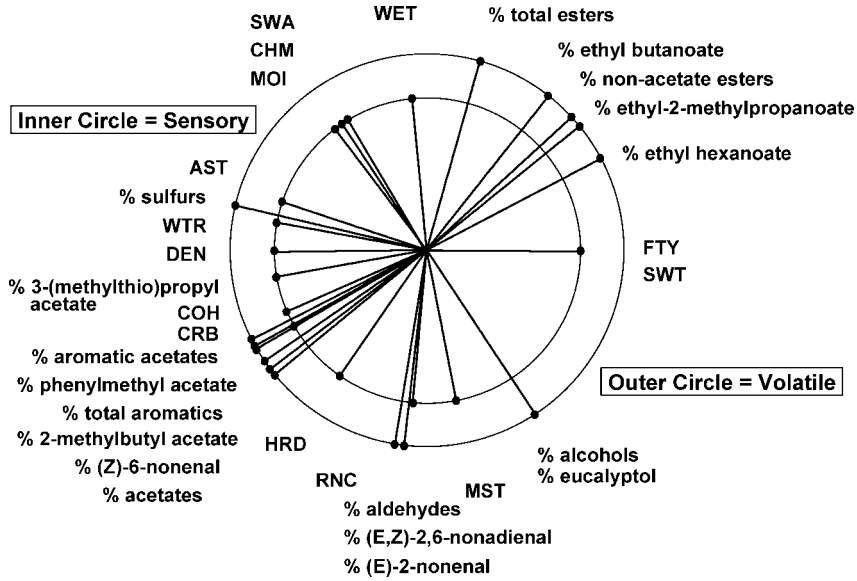

Figure 1. Sensory versus volatile correlations in fresh-cut cantaloupe stored 14 days at 4 °C (year by maturity by day means, Y × M × D). Sensory attributes are FTY = fruity, SWT = sweet taste, MST = musty, RNC = rancid, HRD = hardness, CRB = cucurbit, COH = cohesiveness, DEN = denseness, WTR = water-like, AST = astringent, MOI = moisture release, CHM = chemical, SWA = sweet aromatic, and WET = wetness.

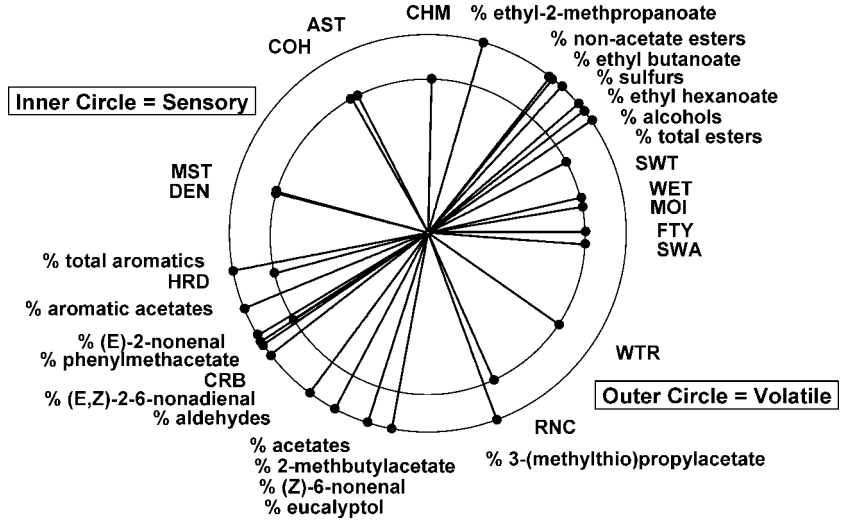

Figure 2. Sensory versus volatile correlations in fresh-cut cantaloupe stored 14 days at 4 °C. Correlation data of the year by day (Y × D) means were used to deliver four maturity levels that were then averaged together. Sensory attributes are FTY = fruity, SWT = sweet taste, MST = musty, RNC = rancid, HRD = hardness, CRB = cucurbit, COH = cohesiveness, DEN = denseness, WTR = water-like, AST = astringent, MOI = moisture release, and CHM = chemical.

Table 3. Correlations between Sensory Attributes and Volatile Compound Classes[a] in Fresh-Cut Cantaloupes Harvested at Various Maturities and Stored up to 14 Days at 4 °C[b]

compound class[a]	FTY[c]	CRB	WTR	SWT	HRD	COH	DEN
non-acetate esters	0.47/0.000[d]	**−0.74/0.000**	−0.51/0.000	0.54/0.000	*−0.68/0.000*	**−0.73/0.000**	−0.54/0.000
acetates	−0.48/0.000	**0.74/0.000**	0.54/0.000	*−0.56/0.000*	*0.67/0.000*	**0.73/0.000**	*0.57/0.000*
total esters	0.17/0.226	−0.52/0.000	−0.06/0.668	0.20/0.174	*−0.55/0.000*	−0.41/0.004	−0.14/0.320
aromatic acetates	*−0.56/0.000*	*0.56/0.000*	0.31/0.000	*−0.56/0.000*	**0.71/0.000**	*0.65/0.000*	*0.65/0.000*
total aromatics	−0.52/0.000	*0.57/0.000*	*0.58/0.000*	−0.52/0.000	**0.73/0.000**	*0.66/0.000*	*0.63/0.000*
sulfur compounds	*−0.58/0.000*	0.50/0.000	*0.66/0.000*	*−0.58/0.000*	0.27/0.058	0.52/0.000	*0.67/0.000*

[a] Compound classes are according to **Table 1**. Additionally, "aromatic acetates" (benzyl ring) comprised benzyl acetate, ethyl phenylacetate, and phenylethyl acetate, while "total aromatics" comprised eight benzyl ring compounds (benzyl acetate, ethyl phenylacetate, phenylethyl acetate, benzyl alcohol, phenyl ethyl alcohol, benzenepropanol, benzaldehyde, and benzeneacetaldehyde). Total esters were the sum of 17 non-acetates and 11 acetates. [b] Year by maturity by day means, Y × M × D. [c] FTY = fruity, CRB = cucurbit, WTR = water-like, SWT = sweet taste, HRD = hardness, COH = cohesiveness, and DEN = denseness. [d] Data reflect the coefficient of correlation, *r*, followed by the *p* value for the test of the null hypothesis, H_o: $r = 0$. Significant correlations considered moderate (≥ ± 0.55) are indicated with italics, and strong correlations (≥ ± 0.70) are in boldface.

and therefore were not presented in **Tables 3** and **4**. Unfortunately, statistically combining the 4 maturity levels (Y × M × D) obscures the fact that the highest acetate and aldehyde levels were found in 1/4-slip samples (*4*). Maturity trends for acetates

Table 4. Correlations between Sensory Attributes and Specific Volatile Compounds in Fresh-Cut Cantaloupes Harvested at Various Maturities and Stored up to 14 Days at 4 °C[a]

compounds	FTY[b]	CRB	WTR	SWT	HRD	COH	DEN
ethyl 2-methylpropanoate	0.42/0.002[c]	**−0.73/0.000**	−0.54/0.000	*0.55/0.000*	*−0.65/0.000*	*−0.65/0.000*	*−0.58/0.000*
ethyl butanoate	0.35/0.014	*−0.65/0.000*	−0.36/0.010	0.41/0.003	*−0.68/0.000*	*−0.64/0.000*	−0.43/0.002
ethyl 2-methylbutanoate	0.15/0.287	*−0.62/0.000*	−0.20/0.175	0.25/0.078	*−0.61/0.000*	−0.54/0.000	−0.30/0.037
3-methylbutyl acetate	0.25/0.087	*−0.62/0.000*	*−0.59/0.000*	0.50/0.000	−0.36/0.011	−0.49/0.000	−0.52/0.000
2-methylbutyl acetate	−0.53/0.000	**0.70/0.000**	*0.59/0.000*	*−0.60/0.000*	*0.62/0.000*	**0.73/0.000**	*0.59/0.000*
ethyl hexanoate	*0.61/0.000*	**−0.77/0.000**	**−0.70/0.000**	**0.73/0.000**	−0.53/0.000	*−0.68/0.000*	−0.65/0.000
hexyl acetate	−0.22/0.128	0.33/0.022	0.20/0.175	−0.18/0.216	0.38/0.006	*0.60/0.000*	0.26/0.075
(*Z*)-6-nonenal	−0.42/0.002	*0.59/0.000*	0.52/0.000	*−0.58/0.000*	0.50/0.000	0.47/0.001	0.46/0.001
3-(methylthio)propyl acetate	*−0.68/0.000*	**0.72/0.000**	**0.85/0.000**	**−0.78/0.000**	0.43/0.002	*0.59/0.000*	**0.79/0.000**
benzyl acetate	*−0.57/0.000*	*0.58/0.000*	*−0..61/0.000*	*−0.57/0.000*	**0.72/0.000**	*0.65/0.000*	*0.65/0.000*
eucalyptol	0.41/0.004	−0.13/0.383	*−0.61/0.000*	*0.56/0.000*	0.15/0.303	−0.12/0.420	−0.50/0.000

[a] Year by maturity by day means, Y × M × D. [b] FTY = fruity, CRB = cucurbit, WTR = water-like, SWT = sweet taste, HRD = hardness, COH = cohesiveness, and DEN = denseness. [c] Significant correlations considered moderate (≥ ± 0.55) are indicated with italics, and strong correlations (≥ ± 0.70) are indicated by boldface.

are essentially reversed whereby 1/4-slip fruit had significantly higher levels compared with FS fruit, and this trend was also conserved through storage (**Table 1**). Subsequently, data presented per maturity in analogous plots (**Figures 1** and **2**) serves to contrast the relative correlations, per maturity. Another noteworthy difference can be seen in the Y × D plot whereby alcohols and sulfur compounds are closely associated with esters and desirable sensory attributes (**Figure 2**). However, as previously discussed, strictly speaking, the (Y × D) ANOVA should be viewed with caution due to observed year and interaction effects.

Since less mature fruit could skew the overall results, it is not surprising in the (Y × M × D) analysis how acetate levels during storage had negative correlation with several quality attributes considered important (**Figure 1**). This trend was nonetheless also observed in the (Y × D) maturity analysis that was generated to deliver paired maturity means (**Figure 2**). Correlations from both ANOVAs (Y × M × D and Y × D) indicate that acetates, aldehydes, and aromatic benzyl compounds were generally associated with sensory attributes considered undesirable such as hardness (HRD), cucurbit (CRB), and (DEN). On the other hand, sensory attributes considered desirable such as fruity (FTY), sweet taste (SWT), and wetness in the Y × D analysis were associated with non-acetate esters and total esters. Interestingly, the maturity analysis indicates that several sensory attributes such as fruity, sweet taste, sweet aromatic (SWA), wetness and moisture release (MOI) and volatiles (non-acetate esters, sulfur compounds, alcohols, and total esters) tightly clustered and were positively associated (**Figure 2**).

Utilizing this SPME method, five compounds accounted for 67.85% of the total volatile profile, and of the 28 esters analyzed, they comprised 96.84%. On the basis of overall 'Sol Real' results for Y × M × D, 2-methylpropyl acetate (16.55%) was the dominant peak, followed by ethyl hexanoate (13.79%), ethyl butanoate (13.59%), 2-methylbutyl acetate (12.46%), and ethyl 2-methyl butanoate (11.46%). In general, the high abundance acetates were negatively correlated with fruity and sweet taste. These relationships indicate that the relative contribution of aroma compounds to the sensory profile is not always based on prevalence, rather, on concentration threshold, and/or maturity. As an example, we present a plot for a CIFAC compound recovered at a very high relative percentage (13.79%), ethyl hexanoate, which was strongly positively correlated with fruity and sweet taste (**Table 4**, **Figure 3**), and 3-(methylthio)propyl acetate, recovered at low relative percentage (0.16%), having a strong negative correlation (−0.78) with sweet taste (**Table 4**, **Figure 3**). As ethyl hexanoate increased, there was a significant increase in sweet taste score that was

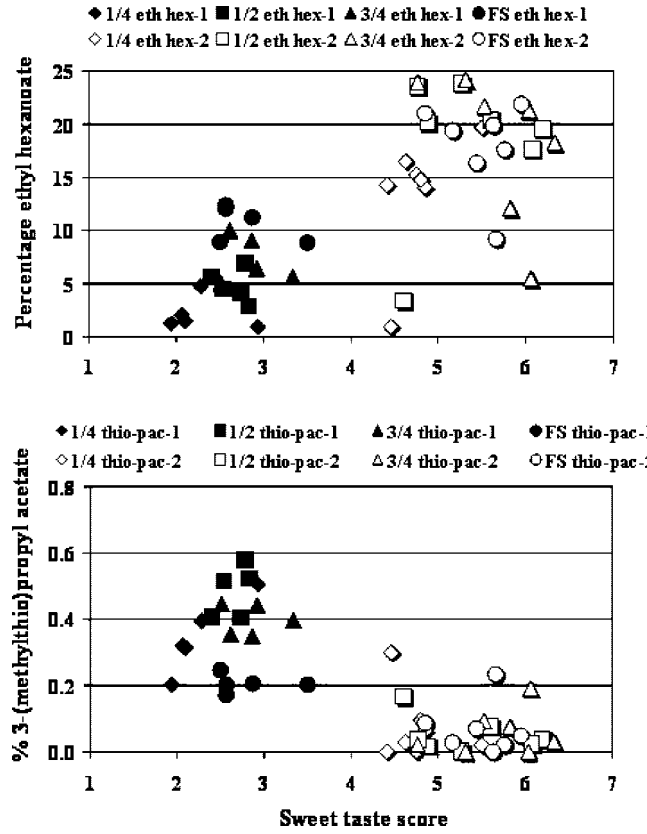

Figure 3. Relative percentage of ethyl hexanoate (eth hex) and 3-(methylthio)propyl acetate (thio-pac) plotted against the sweet taste sensory attribute in fresh-cut cantaloupe stored 14 days at 4 °C, per maturity (1/4-, 1/2-, 3/4-slip, FS), per year (closed symbols year 1, and open symbols year 2).

positively correlated (0.73) across the Y × M × D spectrum. Again, a clear year-effect is evident, and there are definite trends with regard to maturity, as previously reported (*4*).

Acetate ester levels increase during growth and development during ripening of the fruit (*9*) and then decrease as fruit maturity progresses to the overripe stage (*4, 28*). A possible explanation is given by the decomposition of pyruvate (*29*) into ethyl esters and acetate esters. The importance of amino acid precursors would contribute meaningful insight; however, all stored samples we intended to analyze were lost after Hurricane Katrina. Only two volatiles recovered, 3-methylbutyl acetate (0.025%) and 3-methylbutyl hexanoate (0.037%), have leucine as their immediate precursor, whereas several other volatiles including 2-methylbutyl acetate (12.463%), methyl 2-methylbu-

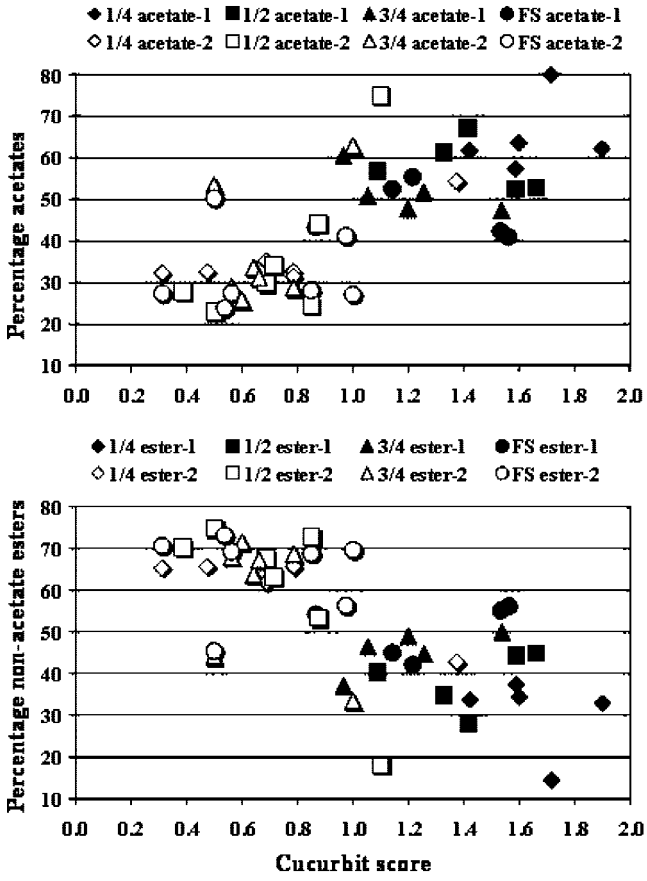

Figure 4. Relative percentage of acetates and non-acetates (esters) plotted against the cucurbit sensory attribute in fresh-cut cantaloupe stored 14 days at 4 °C, per maturity (1/4-, 1/2-, 3/4-slip, FS), per year (closed symbols year 1, and open symbols year 2).

tanoate (5.048%), ethyl 2-methylbutanoate (11.458%), and 2-methyl butylbutyrate (0.117%) have an isoleucine precursor and substantial total percentages. There were three compounds recovered that are derived from valine, methyl 2-methylpropanoate (0.127%), ethyl 2-methylpropanoate (1.399%), and 2-methylpropyl acetate (16.553%), yet only ethyl 2-methylpropanoate is considered a CIFAC. Once pyruvate has metabolized, there is no longer starting material for the formation of the acetate esters, and their concentration likely decreases as they are catabolized or volatized. It is becoming evident that various isoforms of ADH and AAT are expressed in ripening fruits, and these often have substrate specificity and are occasionally not constituently expressed (*24, 30–33*). Therefore, acetate decline during fresh-cut storage might be driven biochemically, especially since some amino acids decrease in fully ripe melons during senescence (*10*). Indeed, volatile ester quantity and synthesis are limited by substrate availability (*34, 35*), as well as by the activity and/or specificity of AAT (*33*). During fresh-cut storage, the relative percentage of acetates decreased and displayed a maturity-dependent linear trend, and there was a significant uniform curvilinear increase in the relative percentage of non-acetate ester/acetate ratio during fresh-cut storage, which was independent of initial processing maturity (*4*). The shift in endogenous ester compounds could be partially responsible for the apparent loss of characteristic flavor in fresh-cut cantaloupe through long-term storage.

Perhaps in the past, high levels of acetates have often been considered overly important as ripening increased. However, we did not perform GC-O or threshold determinations or employ the aromagram technique or quantitative descriptive analysis (QDA) to analyze this in fresh-cut storage. Consumer appraisals were not performed; rather, trained descriptive sensory analysis was utilized. Stage of ripeness often defines consumer preference to like or dislike a given fruit-type or cultivar. This is based on the presences of aldehydes (unripe) giving rise to green/grassy aroma and flavor, versus ripe fruit with esters giving rise to typical fruity profiles (*36*). Subsequently, ascribing likeness similar to a consumer's point-of-view in this paper is unfortunately impossible since panels used descriptors, and we cannot presume if they like/dislike firm, often "cucurbit" (green/grassy) versus sweet, often aromatic fruit (ester volatiles and increasing maturity). Furthermore, our study assessed volatile trends and acetates after harvest, essentially during senescence. More analysis needs to be performed on enzyme systems (i.e., alcohol dehydrogenase, ADH, and alcohol acetyltransferase, AAT) and substrate pools (amino acids and lipids) responsible for CIFAC development immediately prior to harvest. Unfortunately, there are no other similar maturity-related reports in the literature from other fresh-cut climacteric fruits to draw analogies.

There was generally an inverse relationship observed between acetate esters versus non-acetate esters in sensory measures. For example, when acetates were positively correlated with a parameter, such as cucurbit (0.74), cohesiveness (COH, 0.73), and denseness (0.57), non-acetate esters were negatively correlated (**Table 3**). There were generally moderate positive correlations found between non-acetate esters and fruity (0.47), sweet taste (0.54) (**Table 3**), and ethyl hexanoate was correlated with both fruity (0.61) and sweet taste (0.73) (**Table 4**). Interestingly, the opposite trend was normally observed with acetate esters whereby they were negatively correlated with fruity (−0.48) and sweet taste (−0.56) (**Table 3**). Again, specific non-acetate esters such as 2-methylbutyl acetate and benzyl acetate were negatively correlated with fruity (−0.53, and −0.57, respectively) and with sweet taste (−0.60 and −0.57, respectively) (**Table 4**). These correlations were generally conserved in numerous individual compounds as well. For example, 2-methylbutyl acetate (0.70), benzyl acetate (phenylmethyl acetate, 0.58), and 3-(methylthio)propyl acetate (0.72) were positively correlated with cucurbit (**Table 4**). On the other hand, several non-acetate esters such as ethyl 2-methyl propanoate (−0.73), ethyl butanoate (−0.65), ethyl 2-methyl butanoate (−0.62), and ethyl hexanoate (−0.77) were often strongly correlated negatively with cucurbit. Very strong correlations were observed between 3-(methylthio)propyl acetate and various sensory parameters, lending credence to work indicating the relative importance of certain thio compounds in muskmelons (*37*).

Fruity and sweet taste were negatively correlated with percent acetates, aromatic acetates, sulfur compounds, total aromatic compounds, and several individual acetate and aldehyde compounds (**Figure 1**). Fruity and sweet taste were positively correlated with percentage non-acetate esters, alcohols, and various non-acetate compounds and eucalyptol (**Figure 1**). Cucurbit, water-like (WTR, aromatics, excluding chlorine, of minerals and metals commonly associated with tap water), hardness, cohesiveness, and denseness were positively correlated with percentage acetates, aromatic acetates, and total aromatic compounds, and negatively correlated with percentage non-acetate esters. It appears that potentially negative or undesirable attributes like cucurbit and water-like are associated with higher acetates and aromatic (benzyl) compounds.

Hardness was likewise negatively correlated with non-acetates (−0.68) and positively correlated with acetates (0.67) (**Table 3**). Denseness followed the same trend albeit, with weaker

Table 5. Correlations between Sensory Attributes and Volatile Compounds and Compound Classes[a] in Fresh-Cut Cantaloupes Harvested at Various Maturities, Stored at 4 °C[b]

compound or class[a]	FTY[c]	CRB	SWA	WTR	MST	CHM	SWT	AST	WET	HRD	MOI	COH
day 0												
aldehydes	**−0.721**[d]	**0.967**	**−0.794**	**−0.797**	**0.931**	−0.490	**−0.942**	*0.569*	**−0.909**	**0.747**	**−0.956**	0.414
non-acetate esters	*0.616*	**−0.969**	*0.673*	**0.889**	**−0.916**	**0.707**	**0.890**	−0.339	**0.946**	**−0.806**	**0.933**	−0.410
acetates	*−0.592*	**0.962**	*−0.646*	**−0.898**	**0.906**	**−0.742**	**−0.872**	0.293	**−0.946**	**0.812**	**−0.922**	0.408
total esters	**0.713**	**−0.963**	**0.787**	**0.802**	**−0.925**	0.490	**0.947**	*−0.567*	**0.904**	**−0.738**	**0.951**	−0.401
aromatic acetates	**−0.751**	**0.874**	**−0.717**	−0.538	**0.902**	*−0.658*	−0.472	0.254	**−0.945**	**0.995**	**−0.872**	**0.821**
total benzyl aromatics	**−0.794**	**0.897**	**−0.765**	−0.535	**0.928**	*−0.618*	−0.507	0.323	**−0.958**	**0.999**	**−0.900**	**0.832**
alcohols	**−0.828**	**0.996**	**−0.868**	**−0.709**	**0.990**	−0.503	**−0.838**	*0.576*	**−0.972**	**0.876**	**−0.998**	*0.611*
sulfur compounds	0.189	0.226	0.041	*−0.646*	0.091	−0.177	**−0.723**	0.115	−0.084	−0.226	−0.166	*−0.622*
ethyl 2-methylpropanoate	0.450	**−0.902**	0.520	**0.961**	**−0.820**	**0.783**	**0.894**	−0.190	**0.875**	**−0.706**	**0.845**	−0.245
methyl 2-methylbutanoate	**0.934**	**−0.927**	**0.924**	0.459	**−0.975**	0.395	*0.594*	*−0.595*	**0.947**	**−0.959**	**0.957**	**−0.851**
ethyl butanoate	*0.612*	**−0.968**	*0.669*	**0.890**	**−0.915**	**0.715**	**0.884**	−0.329	**0.948**	**−0.810**	**0.932**	−0.413
ethyl 2-methylbutanoate	*0.650*	**−0.974**	**0.714**	**0.870**	**−0.925**	*0.642*	**0.918**	−0.415	**0.939**	**−0.788**	**0.946**	−0.407
3-methylbutyl acetate	−0.244	−0.319	−0.240	**0.713**	−0.213	**0.957**	0.252	*0.653*	0.393	−0.347	0.212	0.074
2-methylbutyl acetate	−0.415	**0.884**	−0.472	**−0.958**	**0.803**	**−0.848**	**−0.835**	0.098	**−0.877**	**0.730**	**−0.822**	0.268
ethyl 2-(methylthio)acetate	*0.647*	**−0.922**	*0.645*	**0.736**	**−0.907**	**0.789**	*0.628*	−0.180	**0.970**	**−0.950**	**0.893**	*−0.650*
ethyl hexanoate	0.489	**−0.919**	0.541	**0.934**	**−0.850**	**0.822**	**0.839**	−0.163	**0.914**	**−0.779**	**0.865**	−0.341
hexyl acetate	**0.986**	*−0.687*	**0.972**	0.048	**−0.787**	−0.121	0.402	**−0.872**	*0.672*	**−0.714**	**0.769**	**−0.836**
ethyl 3-(methylthio)propanoate	*0.640*	**−0.975**	*0.683*	**0.862**	**−0.932**	**0.733**	**0.840**	−0.313	**0.969**	**−0.857**	**0.942**	−0.481
(*Z*)-6-nonenal	−0.289	**0.737**	−0.411	**−0.917**	*0.628*	−0.524	**−0.975**	0.300	*−0.638*	0.372	*−0.683*	−0.096
3-(methylthio)propyl acetate	−0.526	**0.934**	*−0.575*	**−0.918**	**0.872**	**−0.807**	**−0.837**	0.193	**−0.931**	**0.803**	**−0.885**	0.380
(*E*,*Z*)-2,6-nonadienal	**−0.851**	**0.994**	**−0.886**	*−0.678*	**0.995**	−0.483	**−0.815**	*0.592*	**−0.973**	**0.889**	**−1.000**	*0.645*
(*E*)-2-nonenal	**−0.879**	**0.987**	**−0.906**	*−0.634*	**0.999**	−0.458	**−0.779**	*0.608*	**−0.973**	**0.906**	**−0.999**	*0.691*
benzyl acetate	*−0.695*	**0.892**	*−0.672*	*−0.629*	**0.900**	**−0.734**	−0.530	0.197	**−0.957**	**0.981**	**−0.876**	**0.748**
eucalyptol	**−0.809**	**0.998**	**−0.839**	**−0.720**	**0.992**	*−0.573*	**−0.799**	0.501	**−0.991**	**0.915**	**−0.994**	*0.642*
day 9												
aldehydes	0.228	−0.191	0.326	−0.363	**0.928**	0.025	**−0.835**	*−0.639*	**−0.904**	**0.972**	**−0.884**	*0.562*
non-acetate esters	0.480	−0.481	**−0.904**	−0.351	**−0.788**	*0.687*	**0.863**	**0.996**	*0.581*	**−0.845**	*0.688*	0.077
acetates	−0.514	0.515	**0.919**	0.378	**0.771**	**−0.712**	**−0.854**	**−0.999**	*−0.559*	**0.824**	*−0.672*	−0.115
total esters	**−0.979**	**0.963**	**0.873**	**0.763**	0.164	**−0.914**	−0.380	*−0.684*	0.065	0.110	−0.110	**−0.813**
aromatic acetates	*−0.626*	*0.690*	*0.613*	−0.025	**0.760**	−0.364	**−0.867**	**−0.716**	*−0.690*	0.535	**−0.793**	−0.437
total benzyl aromatics	0.208	−0.107	−0.355	**−0.851**	0.496	*0.618*	−0.424	0.105	*−0.698*	0.204	*−0.637*	0.119
alcohols	**0.901**	**−0.940**	*−0.553*	−0.311	−0.232	0.520	0.425	0.441	0.140	0.020	0.280	**0.882**
sulfur compounds	**0.741**	**−0.727**	**−0.995**	*−0.611*	*−0.565*	**0.884**	**0.709**	**0.962**	0.316	*−0.603*	0.465	0.393
ethyl 2-methylpropanoate	**0.870**	**−0.850**	**−0.982**	**−0.730**	−0.384	**0.947**	*0.566*	**0.870**	0.128	−0.397	0.295	*0.587*
methyl 2-methylbutanoate	−0.449	0.452	**0.886**	0.317	**0.809**	*−0.658*	**−0.876**	**−0.992**	*−0.609*	**0.866**	**−0.711**	−0.043
ethyl butanoate	0.497	−0.505	**−0.897**	−0.317	**−0.812**	*0.668*	**0.889**	**0.996**	*0.613*	**−0.845**	**0.722**	0.102
ethyl 2-methylbutanoate	*0.688*	**−0.700**	**−0.936**	−0.397	**−0.733**	**0.745**	**0.857**	**0.977**	0.529	**−0.704**	*0.664*	0.342
3-methylbutyl acetate	**0.995**	**−0.991**	*−0.692*	*−0.669*	−0.007	**0.775**	0.233	0.470	−0.167	0.127	−0.001	**0.947**
2-methylbutyl acetate	*−0.554*	*0.553*	**0.936**	0.415	**0.746**	**−0.742**	**−0.840**	**−1.000**	−0.528	**0.795**	*−0.647*	−0.161
ethyl 2-(methylthio)acetate	**0.850**	**−0.808**	**−0.951**	**−0.868**	−0.188	**0.996**	0.375	**0.777**	−0.086	−0.261	0.079	*0.593*
ethyl hexanoate	0.247	−0.241	**−0.798**	−0.255	**−0.798**	*0.565*	**0.820**	**0.939**	*0.610*	**−0.922**	*0.683*	−0.178
hexyl acetate	**0.757**	**−0.771**	**−0.936**	−0.429	*−0.682*	**0.766**	**0.824**	**0.950**	0.478	*−0.628*	*0.622*	0.439
ethyl 3-(methylthio)propanoate	**0.844**	**−0.836**	**−0.982**	*−0.635*	−0.496	**0.898**	*0.667*	**0.913**	0.255	−0.486	0.416	0.544
(*Z*)-6-nonenal	−0.047	0.035	*0.673*	0.167	**0.765**	−0.439	**−0.743**	**−0.845**	*−0.601*	**0.937**	*−0.642*	0.374
3-(methylthio)propyl acetate	**−0.832**	**0.805**	0.357	**0.705**	−0.474	*−0.603*	0.264	−0.033	*0.600*	*−0.573*	0.467	**−0.954**
(*E*,*Z*)-2,6-nonadienal	**−0.850**	**0.834**	**0.988**	*0.691*	0.441	**−0.929**	*−0.615*	**−0.898**	−0.189	0.450	−0.352	*−0.552*
(*E*)-2-nonenal	*−0.580*	*0.582*	**0.938**	0.406	**0.751**	**−0.741**	**−0.851**	**−1.000**	−0.536	**0.784**	*−0.659*	−0.194
benzyl acetate	*−0.665*	**0.699**	**0.843**	0.225	**0.798**	*−0.610*	**−0.914**	**−0.923**	*−0.641*	*0.695*	**−0.765**	−0.359
eucalyptol	*−0.681*	*0.606*	**0.778**	**0.987**	−0.153	**−0.948**	−0.011	−0.529	0.426	0.023	0.286	−0.490

[a] Compound classes are according to **Table 1**. Additionally, "aromatic acetates" (benzyl ring) comprised benzyl acetate, ethyl phenylacetate, and phenylethyl acetate, while "total aromatics" comprised eight benzyl ring compounds (benzyl acetate, ethyl phenylacetate, phenylethyl acetate, benzyl alcohol, phenyl ethyl alcohol, benzenepropanol, benzaldehyde, and benzeneacetaldehyde). Total esters were the sum of 17 non-acetates and 11 acetates. [b] Data for year × day (Y × D) means were used to deliver four maturity levels that were averaged to deliver paired maturity means for correlations on selected days. [c] FTY = fruity, CRB = cucurbit, SWA = sweet aromatic, WTR = water-like, MST = musty, CHM = chemical, SWT = sweet taste, AST = astringent, WET = wetness, HRD = hardness, MOI = moisture release, and COH = cohesiveness. [d] Data reflect the coefficient of correlation, *r*, followed by the *p* value for the test of the null hypothesis, H_o: $r = 0$. Significant correlations considered strong ($\geq \pm 0.70$) are in boldface, and moderate ($\geq \pm 0.55$) are italicized.

correlation. Hardness was also positively and strongly correlated with aromatic acetates (0.71) and all aromatic (benzyl) compounds (0.73). However, these attributes are likely simply correlated as general consequences of ripening and senescence. In general, cohesive, harder, and denser tissue had more acetates and cucurbit notes, and lower levels of non-acetate esters were associated with softer tissue containing less cucurbit notes. The relationship between the aforementioned volatiles and sensory attributes was illustrated by comparing 1/4-slip through FS cubes (**Figure 4**). Since most correlations presented are Y × M × D, the maturity-effect and year-effect were hard to envision. Subsequently, selected data were plotted to display obvious year-effects, mainly attributed to quantitative volatile differences, as previously described (*4*), quality differences (*11*), and the general maturity-effect. Cubes prepared from 1/4-slip fruit contained higher cucurbit notes (*8*) and greater levels of acetates in each year (*4*), and contrarily less non-acetate esters compared with progressively more mature samples.

In the Y × D analysis with maturity means paired, several sensory attributes were often highly correlated with volatile classes and specific compounds (**Table 5**). As one would expect, separating out maturity by day delivered substantially higher

Table 6. Correlations between Physiological Measures and Volatile Classes[a] in Fresh-Cut Cantaloupes Harvested at Various Maturities and Stored up to 14 Days at 4 °C[b]

compound class	*L**	firmness	color	desiccation	average	bioforce[c]	bioarea	slope	TA	MPa
aldehydes	0.38/0.009[d]	*0.64/0.000*	0.29/0.041	0.40/0.004	0.46/0.001	**0.74/0.000**	**0.75/0.000**	**0.72/0.000**	**0.74/0.000**	*0.59/0.005*
non-acetate esters	*−0.63/0.000*	*−0.66/0.000*	*−0.59/0.000*	**−0.77/0.000**	*−0.61/0.000*	*−0.67/0.001*	*−0.66/0.001*	*−0.69/0.001*	**−0.70/0.000**	**−0.79/0.000**
acetates	*0.63/0.000*	*0.64/0.000*	*0.60/0.000*	**0.78/0.000**	*0.60/0.000*	*0.64/0.002*	*0.63/0.002*	*0.65/0.001*	*0.66/0.001*	**0.78/0.000**
total esters	−0.46/0.002	*−0.62/0.000*	−0.36/0.011	−0.48/0.000	−0.49/0.000	**−0.73/0.000**	**−0.73/0.000**	**−0.73/0.000**	**−0.74/0.000**	*−0.65/0.001*
aromatic acetates	*0.57/0.000*	0.54/0.000	0.43/0.002	**0.71/0.000**	0.49/0.000	*0.66/0.001*	*0.64/0.002*	**0.73/0.000**	**0.72/0.000**	**0.88/0.000**
total aromatics	*0.59/0.000*	*0.58/0.000*	0.46/0.001	**0.71/0.000**	0.53/0.000	*0.66/0.001*	*0.64/0.002*	**0.73/0.000**	**0.72/0.000**	**0.89/0.000**

[a] Volatile classes described in **Tables 1** and **2**. [b] Year by maturity by day means, Y × M × D. [c] Instrumental texture measures reported are bioforce = force (N) at the bioyield point; bioyield area (Ns); slope of the force deformation curve (N s^{-1}) until the first inflection point which indicates the point of nondestructive elastic deformation; TA = total force area (Ns); and MPa = Young's modulus. [d] Significant correlations considered moderate (≥ ± 0.55) are indicated with italics, and strong correlations (≥ ± 0.70) are indicated by bold font.

correlations. For example, FTY was strongly positively correlated with total esters (0.713) and hexyl acetate (0.986) on day 0 (**Table 5**). Contrarily, FTY was negatively correlated with aldehydes (−0.721), total aromatics (−0.794), and alcohols (−0.828), and individual compounds within these classes on day 0. SWA and SWT displayed essentially the same trends with these volatiles, exhibiting very strong correlation (generally ≥ ± 0.90). Again, reversed correlations were observed for CRB and HRD with several volatiles. For example, CRB was strongly positively correlated with aldehydes (0.967), acetates (0.962), and total aromatics (0.897), yet negatively correlated with non-acetates (−0.969) (**Table 5**). Interestingly, the correlative trends (positive versus negative associations) occasionally reversed from day 0 through to day 9 (**Table 5**). One attribute displayed an interesting trend whereby almost all correlations reversed (negative versus positive) from day 0 to 9, and most moderate to strong correlations were only observed in day 9 (**Table 5**). Reversal in correlations was also occasionally observed between days 0 and 9 in the SWA, FTY, and CRB attributes (e.g., total esters, alcohols, and several individual compounds in SWA). After 5 days' storage, very few correlations were observed in the Y × D paired maturity analysis (data not shown), even though days 5–7 corresponded with the maximum recovery of most compounds in all maturities (*4*). Strangely, AST and HRD had the predominant correlations observed in day 5 (data not shown). In general, greater significant correlations were observed in the ANOVA with maturity means paired (Y × D), and the shifts (positive to negative or vice versa) in several associations from day 0 to 9 may give an indication of the relative importance of initial processing maturity and how perception of attributes along with their associated volatiles varied markedly through storage.

Physiological and Volatile Correlations. In general, it is sometimes difficult to rationalize why certain parameters were highly correlated. Such instances were found between *L** and non-acetate esters (−0.63) and esters (0.63) (**Table 6**). Subjective determination of color delivered the same basic result whereby it was positively correlated with acetates (0.60) and negatively correlated with non-acetate esters (−0.59). On the other hand, following suit as the above inverse comparisons relating textural attributes to volatiles, subjective appraisal of desiccation was strongly correlated positively with acetates (0.78) and negatively correlated with non-acetates (−0.78) (**Table 6**). Numerous strong positive correlations were found between acetates and subjective firmness (0.64), and all five instrumental measures of texture: bioforce (0.64), bioarea (0.63), slope (0.65), total area (0.66), and Young's modulus, MPa (0.78) (**Table 6**). Young's modulus (MPa) was highly correlated with relative percentage aromatic acetates (0.88), total aromatic (benzyl) compounds (0.89), and acetates (0.78), and negatively correlated (−0.79) with non-acetate esters (**Table 6**). These were among the most robust correlations observed in the entire study. We previously reported that all instrumental measures of texture were significantly and highly correlated (positively) with hardness, and negatively correlated with wetness (*8*). These data for 'Sol Real', a traditional western shipper (WS) cultivar, and other similar data we reported for both Athena (an eastern shipper cantaloupe) and several WS cultivars (*13*) indicate that increasing relative percentage of acetates are significantly correlated with increased firmness and hardness.

Interestingly, total esters (non-acetates plus acetates) were strongly negatively correlated with firmness. Since an inverse relationship was generally observed between the two main ester classes, it is subsequently difficult to ascribe how and why the aggregate summed esters are consistently negatively correlated with texture. Nonetheless, once again, the generality was found in that acetates were positively correlated with firmness (**Table 6**), and this was conserved in several specific acetate compounds (data not shown). Aldehydes were associated with immature and less mature fruit (*4*, *9*), and subsequently the correlation data confer that textural measures were strongly and positively correlated with two of the most important flavor-related aldehydes, (*E*,*Z*)-2,6-nonadienal and (*E*)-2-nonenal. Benzyl acetate was also strongly positively correlated with instrumental measures of firmness such as slope of the force deformation curve (0.73), total force area under the curve, TA (0.73), and desiccation (0.72). The most robust correlation (Y × M × D) of the entire study was observed between Young's modulus and total aromatic compounds (0.89, **Table 6**), and benzyl acetate (0.89).

Fresh-cut cantaloupe tissue is predominately composed of thin nonlignified walls that are structurally weak compared to vegetative tissue (*5*). Softening, due in part to cell rupture, occurs naturally during senescence and in overripe fruit. Beyond cutting, this effectively may also facilitate organelle disruption and allow enzymatic activities to proceed, resulting in flavor changes. Esterified phenolic components of the cell walls may be released during aging and in fresh-cut storage as well, and this will decrease adhesion properties subsequently resulting in softening and release of additional volatile substrates. Subsequently, the level of acetates, aromatic acetates and benzyl compounds might be used as an indicator of firmness while developing new cultivars for improved firmness.

Sensory and Physiological Correlations. As previously mentioned, it is oftentimes difficult to rationalize why certain parameters were highly correlated. Such instances were found between color measures (*L**, *a**, *b**, *a**/*b**) and fruity, cucurbit, water-like, and sweet taste. Some of the strongest sensory × physiological correlations were attained between sweet taste and *a** (0.83), *b** (0.71), *a**/*b** (0.81), and %Brix (0.78). Many other moderate to strong correlations occurred between various firmness measures and sensory texture attributes however, much

of this data was previously reported (*8*). Cucurbit, denseness, and water-like were negatively correlated with *a**, *b**, *a**/*b** and %Brix, and positively correlated with *L** and desiccation (data not shown). Fruity and sweet taste were positively highly correlated with *a** (0.72, 0.83, respectively), *b** (0.63, 0.71), *a**/*b** (0.69, 0.81), and %Brix (0.68, 0.78). Fruity and sweet taste clustered tightly with %Brix, color and pH (data not shown), and this was expected.

Conclusion. To the best of our knowledge, this study, including refs (*4, 8, 11*), was the first to comprehensively evaluate volatile, quality, and sensory differences in fresh-cut cantaloupes prepared from several distinct initial maturity stages and attempt to statistically correlate quality measures. There is high probability that the visualized correlation plots reflect an authentic situation whereby acetates are important during ripening, yet this importance decreases through ripening and as senescence commences, as a stored fresh-cut product. Theoretically, in senescence the correct isoforms of ADH may not be available (*30*), and substrate specific isoforms of AAT (*31*) could effectively run out of necessary precursors to generate additional CIFAC acetates from amino acids and alcohols. This might explain why non-acetate esters appear to increase during fresh-cut storage, at the expense of acetates, resulting in a dramatic non-acetate ester to acetate ratio change that occurs which is independent of initial maturity (*4*). The relative changes in levels of acetates versus non-acetates through storage might explain the occasional reversal in positively versus negatively correlated parameters.

Overall, relatively strong correlations between numerous physiological, volatile, and sensory measures were found in this study. This occurred even though samples were randomized from numerous fruits, per maturity, per EU, over 2 years. Significant volatile correlations were nonetheless found even though numerous SPME fibers were employed over the course of this study to assess and compare about 168 samples. Furthermore, volatile and quality measurements were obtained from different EUs compared with sensory appraisals. Also, there was a significant year or interaction effects for several parameters observed across the study. Subsequently, one would expect stronger correlations if the same EU could have been used for all measurements. Nevertheless, based on our volatile, sensory, and physiological data, it appears that high-quality fresh-cut cantaloupe can be prepared with fruit when harvested from at least 1/2-slip, but not from 1/4-slip, fruit. From the correlations, it appears that "non-acetate esters" are more important determinants of desirable sensory attributes in this melon cultivar. Acetates are often flavor-important in fruits, and their concentrations increase markedly with ripening. Further interpretation, biochemical analysis, and explanation are needed to rationalize why mainly only non-acetate esters were highly correlated with desirable sensory and quality parameters.

ABBREVIATIONS USED

Alcohol acetyltransferase, AAT; alcohol dehydrogenase, ADH; characteristic impact flavor or aroma compounds, CIFAC; experimental unit, EU; solid phase microextraction, SPME.

ACKNOWLEDGMENT

We thank Dean Liere and Alex May of Syngenta Seeds, Inc.; ROGERS Brand Vegetable Seeds, for supplying cantaloupe fruit; Karen Bett for providing the trained sensory analysis; and Jeanne M. Lea for laboratory assistance and volatile data analysis.

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Received for review January 31, 2007. Revised manuscript received August 1, 2007. Accepted August 28, 2007. The mention of firm names or trade products does not imply that they are endorsed or recommended by the U.S. Dept. of Agriculture over other similar firms or products not mentioned.

JF070282N