Effect of Harvest Maturity on the Sensory Characteristics of Fresh-cut Cantaloupe

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ABSTRACT: Maintaining flavor, aroma, microbial, and postharvest quality after processing and throughout the distribution chain is a major challenge facing the fresh-cut fruit industry. Flavor and aroma are most often the true indicators of shelf-life from the consumer's point of view. Changes in post-cutting sensory attributes during fresh-cut storage at 4 °C in cantaloupe harvested at 4 distinct maturities (¼, ½, ¾, and full slip) were subsequently investigated. Trained descriptive sensory panelists were used in a 2-y study to assess sensory differences after 0, 2, 5, 7, 9, 12, and 14 d. A texture analyzer was also used in an attempt to verify textural properties revealed by the panelists. The ¼-slip harvested fruit were firmer than the other 3 maturities, and ¼-slip cubes retained the most firmness through fresh-cut storage. Correspondingly, fruity and sweet aromatic flavor were significantly less intense in the ¼-slip cubes compared with ½- and ¾-slip maturities. Sweet taste was consistently significantly less intense in the ¼-slip cubes than the other maturities during the entire storage period. Hardness was more intense (harder) in ¼-slip cubes during 0 to 9 d. This trend was almost identical in the instrumental texture determinations for the force and slope at the 1st bioyield point of the force deformation curves. Meanwhile, ¼-slip cubes were significantly less intense than the other maturities in surface wetness and moisture release on day 0 and throughout storage. It appears that fresh-cut cantaloupe cubes with desirable sensorial attributes can be prepared with fruit when harvested ≥½ slip but not from ¼-slip fruit.

Keywords: cantaloupe, fresh-cut, minimal processing, maturity, sensory

Introduction

In one of the most complete taxonomic descriptions for *Cucumis melo* fruit, Naudin (1859) and thereafter Bailey (1939) classified the race (tribe or variety) *cantalupensis* as hard-rinded, rough, deeply grooved (sutured) melons that are never netted (smooth), with salmon or orange-red, sweet flesh. This variety was technically known as rockmelons or cantaloupes, principally in Europe. The *reticulatus* race consists of netted melons but is sometimes plain or almost smooth with orange, greenish orange, green or greenish white flesh, having musky odor, and an ethylene climacteric. This group has been called "nutmeg" melons, "muskmelons," and "cantaloupe," which is the generic trade name is the United States. Yet, cantaloupe is a misnomer considering the original term and classifications for *cantalupensis*. Innumerable intermediate horticultural *C. melo* forms (that is, cultivars) have arisen from various crossings, which have obscured classification of these groups (Naudin 1859; Munger and Robinson 1991). Adding to the confusion, more recently, *Cucumis melo* L. *reticulatus* (netted) and *cantalupensis* (smooth) were combined into 1 group, *cantalupensis*, because of numerous similarities between groups and naming confusion, that is cantaloupe or muskmelon (Munger and Robinson 1991). Nonetheless, as orange-fleshed, netted, climacteric cantaloupe melons mature on the plant, the abscission layer where the stem (peduncle) attaches to the fruit starts to separate. The degree of separation is called "slip." Partial to complete separation at the abscission zone is a good indicator of full ripeness and harvest time. In the United States, the commercial practice for harvesting cantaloupe is to wait until melons are ¾ slip or full slip.

Fully ripe orange-fleshed cantaloupes are highly regarded for their unique flavor, and high sugar levels are often the determinant of quality (Yamaguchi and others 1977). Consumer acceptance of melons is driven most often by sweetness (sucrose) (Bianco and Pratt 1977) and also by an acceptable aroma bouquet or presence of volatiles. Increasing melon fruit maturity is related well with increased ester and volatile recovery (Pratt 1971; Yabumoto and others 1978; Horvat and Senter 1987; Wyllie and others 1996; Beaulieu and Grimm 2001; Beaulieu 2004). Fruit harvested before development of the abscission zone will not develop similar flavor or volatiles compared with fruit that remained on the vine a longer period of time (Pratt 1971; Wyllie and others 1996; Beaulieu and Grimm 2001). Yet, fruit harvested at or after development of the abscission have a shorter storage life and flavor loss may occur before completion of the marketing process (Hoover 1955).

Fresh-cut produce is the fastest growing food category in U.S. supermarkets. The fresh-cut industry has consistently grown by approximately 10% per year since 1995 and sales are expected to be $14 billion in 2003 (Anonymous 1999a). Fresh-cut fruit sales have grown in a linear manner, at roughly $1 billion per year (Anonymous 1999b), largely because of increased regional production and distribution. Melons and fresh-cut melons are rapidly gaining a large share of the produce market (Bareuther 2000) and therefore, a substantial monetary incentive exists to improve their intrinsic qualities. However, cutting tissue causes major tissue disruption and shortens shelf-life as sequestered enzymes and substrates become mixed (Wiley 1994; Watada and Qi 1999; Toivonen and DeEll 2002).

Within the fresh-cut fruit industry, shelf-life considerations have largely been based on appearance, neglecting flavor and texture. Yet, flavor and consumer acceptance are critical for repeat buyers of fresh-cut cantaloupe (Anonymous 2000; Bareuther 2000; Beaulieu 2001; Beaulieu and Baldwin 2002). Unfortunately, in stored fresh-cut fruit, flavors tend to deteriorate at a quicker rate than appearance does (Ayhan and others 1998). Subsequently, because a firm prod-

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uct is desired for improved shipping, handling, and storability, fruit destined for cutting is occasionally 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 (Gorny and others 1998; Beaulieu and others 1999; Gorny and others 2000; Beaulieu and Lea 2003b). Such problems are exacerbated with out-of-season, imported fruits because of extended shipping that requires fruit to be harvested even less mature. On the other hand, full-slip harvest, marketing or cutting, and packaging appear to shorten shelf-life because of reduced product firmness. We have established that harvest maturity significantly affects the level of flavor volatiles extracted from 'Sol Real' cantaloupes (Beaulieu and Grimm 2001; Beaulieu 2004). Similarly, 'Makdimon' melons harvested 2 d before fully ripe (full slip) developed only about 1 quarter the total volatiles as compared with 3-d-old fully ripe fruit (Wyllie and others 1996).

Minor physiological differences in initial fruit quality appear to translate to substantial differences in the quality of the cut product. The ever-expanding fresh-cut industry is therefore pressuring farmers to carefully plant specific cultivars, with harvest maturity and end-use in mind. However, decisions regarding choice of cultivar and harvest maturity are often based empirically, and change over region and season, and for imported fruit. Hence, it remains a challenge to present the consumer an optimal fresh-cut cantaloupe product with both keeping quality and desirable flavor attributes. Research geared toward discovering how and why flavor and texture qualities vary based on harvest maturity and then change and/or decline during fresh-cut storage were therefore investigated.

Materials and Methods

Melon culture and harvest maturity

Orange-flesh cantaloupes (*Cucumis melo* var. reticulatus, Naud. cv. 'Sol Real') were grown in Kettleman City, Calif. (year 1) and Five Points, Calif. (year 2) on raised beds with standard cultural practices in a commercial field with furrow irrigation. At full bloom, about 4000 to 6000 flowers were anthesis-tagged in 1 morning during peak flowering. To ensure a higher percentage of fruit set, developing fruit proximal to tagged flowers were removed upon tagging. Maturity was carefully monitored in the field by flagging tagged fruit approaching commercial harvest (¾ slip). In year 1, fruit were harvested 38 d after anthesis (DAA) at 4 distinct maturities: ¼, ½, ¾, and full slip, field hydro-cooled in an ice slurry, stored over the weekend at approximately 5 °C, packaged and freighted overnight to the Southern Regional Research Center (USDA-ARS-SRRC, New Orleans, La., U.S.A.) for analysis. In year 1, 5 d elapsed between harvesting and fresh cutting; and in year 2, ripe fruit were harvested 37 DAA, with 4 d storage at approximately 5 °C before fresh cutting. After discovering little to no fungal or bacterial decay after 9 d storage in the 1st year, the fresh-cut shelf-life portion was extended in year 2 to 14 d.

Fresh-cut and sample preparation

Fruit (approximately 35 to 40 per maturity, about 60 kg) were inspected carefully for bruising and compression damage and culled if not in optimal condition. Fruit were washed thoroughly in cold running tap water then sanitized in 100 μL/L bleach (5.25% NaClO, pH approximately 6.7), rinsed in deionized water (4 °C), and uniformly peeled on a Muro CP-44 Melon Peeler (Tokyo, Japan). The stem and blossom portions (approximately 2 to 3 cm) were removed, and each melon was sliced once longitudinally, seeds were removed, and the seed cavity was cleaned. Halves were cut into approximate 2.5-cm equatorial slices, from which all loose endocarp seed cavity tissues (1 to 2 mm thick) was removed, and approximately 2- to 3-cm × 2.5-cm cubes were prepared (Beaulieu and Lea 2003a). Processing was done under strict sanitary conditions, using good manufacturing practices, in a food preparation kitchen. For fresh-cut storage, cubes from numerous groups of 5 to 6 fruit were randomized, and approximate 300-g cubes were placed into each 24-ounce (approximately 1 L) low-profile Juice Catcher container (SRW-24-JC, Winkler Forming Inc., Carrollton, Tex., U.S.A.), with about 25 kg final product packaged, per maturity. Containers were stored at 4 °C and fresh-cut cubes were assessed after 0, 2, 5, 7, 9, 12, and 14 d.

Instrumental texture evaluation

On each day, 10 fresh-cut cubes, per maturity, were selected and carefully trimmed on each side to 1 cm with 2 razor blades mounted in a stainless-steel device. A force to 75% of original size compression test was performed in perfect 1-cm³ cubes on a Texture Technologies, Stable Micro System Texture Analyzer TA.XT2 (Scarsdale, N.Y., U.S.A.). A 4-cm-dia flat compression probe was used at 100 g force (0.981 N). Because specimen orientation significantly affects resultant mechanical textural properties in apple (Abbott and Lu 1996), cubes were always compressed with the original rind-side down. Pretest speed was 10.0 mm/s and then test speed was 0.5 mm/s, followed by return post-test speed of 10.0 mm/s. The slope of the force deformation curve (N/s) until the 1st inflection point (which indicates the point of nondestructive elastic deformation), force (N) at the bioyield point, bioyield area (N*s), total force area (N*s), and Young's Modulus (MPa) were determined in each sample ($n = 10$). Instrumental texture was analyzed only in year 1.

Sensory evaluation

Nine trained panelists, having 1- to 8-y experience in descriptive sensory analysis techniques, evaluated cantaloupe samples during both years of the experiment at the SRRC. Panelists were selected because of normal abilities to taste, smell, and differentiate between intensities for flavor and texture, after 6 mo of training. The Spectrum® (Sensory Spectrum, Inc., Chatham, N.J., U.S.A.) intensity scale for descriptive analysis was followed, with supplemental texture scales developed in-house (Bett 2002). Nine flavor, taste and mouth feel attributes, and 5 texture attributes (Table 1) were evaluated (Bett-Garber and others 2003). Flavor and texture attributes were rated on a 0- to 15-point anchored intensity scale (Table 2), with 0 = not detectable and 15 = more intense than most foods (Meilgaard and others 1999). Flavor references used were stated in the definitions and were previously described (Civille and Lyon 1996; Bett 2002).

While in a food preparation laboratory, 5 cubes were placed in glass custard cups, covered with inverted watch glasses, and equilibrated to 24 °C for 1 h. The cups were labeled with 3-digit random numbers and presented randomly each session to panelists in booths under red lights. Panelists are trained to avoid letting their preferences taint their objective evaluations, but possibly still made preconceived judgments about the flavor when they notice color. During this study, our trained panelists were also assessing numerous varied muskmelons (cream to green to orange flesh); therefore, eliminating any bias attributed to color, over time, was imperative. Experimental control was accomplished by systematically using red lights in all our analyses. Panelists slid the watch glass back to allow the headspace to enter their nose. They evaluated the intensities of the various aromas emitted from the samples. Then they placed 1 cube in their mouth and chewed to prepare for swallowing, but expectorated the sample. If the flavor

Table 1—Flavor and texture descriptors used for fresh-cut cantaloupe

Flavor	
Fruity/melon	A mixture of aromatics associated with melons (cantaloupe, honeydew, watermelon, and so forth) and other fresh fruit
Cucurbit	Aromatics associated with cucurbits such as pumpkins, cucumbers, and squash
Sweet aromatic	The aromatic associated with materials that also have a sweet taste such as honey, caramelized sugar, and cotton candy
Water-like	Aromatics of the minerals and metals commonly associated with tap water. This excludes any chlorine aromatics that may be perceived.
Musty	Aromatic associated with mold or dirt such as geosmin and 2-methyl isoborneol
Chemical	Aromatics commonly associated with solvents, cleaning compounds, and hydrocarbons
Sweet taste	The taste on the tongue associated with sugars
Texture	
Surface properties	
Wetness	The amount of moisture, because of an aqueous system, on the surface 3.0; internal surface of raw carrots → 15.0; water
First compression properties	
Hardness	The force to compress between molars 1.0; cream cheese → 11.0; shelled almonds
Moisture release	Amount of wetness/juiciness released from the sample 2.0; Betty Crocker Gushers → 12.0; grapes
Cohesiveness	Degree to which a sample deforms rather than crumbles, cracks, or breaks 1.0; corn muffin → 12.5; Starburst candy chews
Denseness	The compactness of the cross-section. 2.5; marshmallow → 13.0; Farley fruit slices

descriptor was observed with a different intensity in aroma or flavor by mouth or in 2 different cubes, then the panelist recorded an estimated average. Panelists rinsed with filtered water between samples and used unsalted saltine crackers to cleanse their palates. A warm-up sample (an unidentified variety of cantaloupe) was presented 1st to reduce the 1st sample position bias. Thereafter, the experimental samples were presented monadically in random order within a session. All panelists received the samples in the same order because of limitations in the electronic ballot software. Yet, treatment presentation order was randomized for each session, over both years. All treatment samples for a given storage day (such as day 0) were presented at 1 session. Cantaloupe cubes from both years were evaluated under the same conditions. Both years of data were combined for statistical analysis; however, there were no measures for days 12 and 14 in year 1.

Table 2—Universal flavor intensity scale descriptors and standard references according to the Spectrum® method (Meilgaard and others 1999)[a]

Descriptor	Reference	Intensity
Sweet	1% Sucrose	1
Cooked wheat	Wheat Thins	1
Oil	Frito Lay Potato Chips	2
Diacetyl	Land-O-Lakes Margarine	3
Sweet	Nabisco's Ritz Cracker	4
Apple	Mott's Natural Apple Sauce	5
		6
Orange	Minute Maid Orange Juice	7
		8
		9
Grape	Welch's Grape Juice	10
		11
		12
Cinnamon	Big Red Chewing Gum	13

[a]The universal scale applies an intensity to a given attribute independent of that attributes perceived flavor or aroma in a given product.

Headspace solid phase micro-extraction gas chromatography/mass spectrometry analysis

On each sampling date, volatile samples were prepared in triplicate (container was the experimental unit) from 300 g of randomized fresh-cut cubes from a minimum of 5 fruit per container, per maturity, as previously described (Beaulieu and Grimm 2001). Tissue was rapidly juiced (approximately 15 s) into a slurry with a Braun MP80 Juicer (Braun GmbH, Kronberg, Germany), a 3-mL slurry (without foam) was immediately pipetted into 10-mL glass vials containing 1.1 g NaCl, then 2-methylbutyl 3-methylbutanoate internal standard (IS) was added. Vials were placed on a Combi-Pal Autosampler (Leap Technologies, Carrboro, N.C., U.S.A.) cooling rack at 4 °C. Vials were equilibrated 10 min via oscillation in a 40 °C autosampler, and then a 1-cm 100-mm polydimethylsiloxane (PDMS) solid-phase micro-extraction (SPME) fiber was inserted into the headspace for 12.5 min at 40 °C. Volatile compounds were analyzed at approximately the temperature at which mastication occurs in the human palate (approximately 37 °C), for comparison with trained sensory panelists. Vials were continuously swirled during SPME adsorption with an agitation speed of 100 rpm. Fibers were desorbed at 250 °C for 1 min in the injection port of an HP6890/5973 GC-MS (Hewlett Packard, Palo Alto, Calif., U.S.A.) with a DB-5 (crosslinked 5% phenyl methyl silicone, J&W Scientific, Folsom, Calif., U.S.A.) column (30 m, 0.25-mm inner dia, 25-mm film thickness) for 30-min runs. Data were collected with HP ChemStation software (A.03.00) and searched against the Wiley registry of mass spectral data (7th edition, Palisade Corp., Newfield, N.Y., U.S.A.). Compounds were preliminarily identified by library search and then their identity was confirmed by standard comparisons, GC retention time (RT), MS ion spectra, and an in-house retention index (RI) (Beaulieu and Grimm 2001). Selected unique qualifying target ion responses, per compound, were used to attain an integrated compound response. Data were expressed as averaged target response, in triplicate ($n = 3$), combined over the 2 y. Eleven ester compounds (2-methylpropyl acetate, butyl acetate, 3-

methylbutyl acetate, 2-methylbutyl acetate, unknown alkyl acetate, [Z]-3-hexenyl acetate, hexyl acetate, [E]-3-hexenyl acetate, benzyl acetate, ethyl phenylacetate, phenylethyl acetate) were isolated, analyzed, and grouped as acetates. Seventeen compounds, not containing a methyl group at their R′ terminus, were designated and grouped as non-acetate esters (methyl 2-methylpropanoate, ethyl propanoate, ethyl 2-methylpropanoate, methyl 2-methylbutanoate, ethyl butanoate, ethyl 2-methylbutanoate, ethyl pentanoate, methyl hexanoate, butyl butanoate, ethyl hexanoate, methyl heptanoate, 2-methyl butylbutanoate, ethyl [E]-4-heptenoate, propyl hexanoate, ethyl heptanoate, 3-methylbutyl hexanoate and pentyl hexanoate).

Statistical methods

The experimental design was a randomized complete block design with 9 panelists as block effects and maturity as the treatment effect. The experiment was repeated 5 times in year 1 and 7 times in year 2. Each time the experiment was repeated, the number of days the fruit was stored increased. In an analysis of variance combining all experiments, days of storage was defined as a fixed treatment effect with the year being a replication for days of storage, and panelist treated as subsamples for days of storage. Panelist and year are replicates of maturity treatment. The analysis of variance was accomplished with PROC MIXED (SAS Inst., Release 8.2, 1999-2001, Cary, N.C., U.S.A.). In this analysis, the fixed effects of storage day, maturity, and storage days × maturity were evaluated using the following as random error effects: year, panelists, year by panelists, year by storage day, panelists by storage days within year, year by maturity within storage day. Pairwise mean comparisons for storage days and maturity were computed by Least Significant Difference (LSD) test at $P \leq 0.05$. An addition trend analysis was performed (SAS Inst.) based on the model described previously, with storage day being defined by orthogonal polynomial contrast. The results of this analysis are presented as an attribute explained by a linear or quadratic function of storage days, either averaged over all maturity treatments or shown separately for each maturity treatment, as appropriate. Trends were compared using *F* test for homogeneity of slopes at $P \leq 0.05$. Texture Analyzer data were analyzed using S-PLUS 2000, Professional Release 1, Mathsoft, Inc. (Seattle, Wash., U.S.A.). Data were analyzed as a randomized complete block design with a 2-way treatment structure (5 × 4) with 5 d levels, 0, 2, 5, 7, and 9; and 4 maturity levels, ¼ slip, ½ slip, ¾ slip, and full slip. Each treatment combination had 3 replications (container was the experimental unit), from which 10 cubes were subsampled. Pairwise mean comparisons for fixed effects were computed by least squares means with Tukey's adjustment method, with the probability, $P \leq 0.05$. Instrumental means were constructed by maturity × d to perform a correlation between texture data compared with sensory wetness, hardness, moisture release, cohesiveness, and denseness. The means for the sensory data were taken over panelists, and the means for the instrumental data were taken over juice catcher and cube. Analyses are presented as the coefficient of correlation, *r*, with the *P* value for the *F* test of the null hypothesis (Ho: $r = 0$).

Results and Discussion

Sensory maturity (slip) effect

Overall ANOVA main effects and their associated probabilities for the sensory attributes are summarized in Table 3. The maturity level (amount of abscission or detachment, called "slip") at harvest coincided with significant differences in several flavor attributes (Table 3 and 4). Sweet aromatic flavor and sweet taste significantly increased as maturity increased. Cubes prepared from ¼ slip fruit had significantly lower sweetness compared with the other 3 maturities (Table 4). Sweet aromatic increased significantly from ¼ slip through to ¾ slip; however, a slight decline was observed in full-slip fruit (Table 4). There is generally a significantly conserved increase in numerous volatile compounds as cantaloupe mature (Pratt 1971; Wyllie and others 1996; Beaulieu and Grimm 2001; Beaulieu 2004), but overripe fruit often deviated from this trend (Beaulieu and Grimm 2001), and occasionally full slip diverged slightly as well, especially acetates (Table 5) (Beaulieu 2004). Seed companies and growers have empirically deduced that some cantaloupe cultivars destined for fresh-cutting have an optimum harvest maturity of ¾ slip. These cultivars actually begin to soften and become less desirable (lose flavor and decay faster) if harvested at the full-slip stage (personal communication, D. Liere, Syngenta Seeds Inc.). Subsequently, minor deviations in an otherwise significantly apparent trend could be because of inherent biological variability or ensuing senescence in full-slip 'Sol Real' fruit.

Musty flavor was significantly the lowest in intensity in ¾-slip fresh-cuts (Table 4). Fruity aroma tended to increase, albeit not significantly, with increasing maturity. The ANOVA for cucurbit gave a probability of 0.08, which was only slightly above the α level of 0.05, and cucurbit decreased with increasing maturity, but this will be discussed subsequently. This is highly congruent with our findings,

Table 3—ANOVA probability values from the mixed model for stored fresh-cut cantaloupe prepared from fruit at 4 distinct maturities

	Maturity	Day	Maturity × day
Fruity/melon	0.15	0.29	0.72
Cucurbit	0.08	0.33	0.08
Sweet aromatic	*0.03*[a]	0.43	0.32
Water-like	0.59	0.88	0.84
Musty	*0.01*	*0.02*	0.67
Chemical	0.46	0.82	0.35
Sweet taste	*<0.01*	0.84	0.33
Surface wetness	*<0.01*	0.13	0.44
Hardness	0.17	*<0.01*	0.21
Moisture release	*<0.01*	0.53	0.28
Cohesiveness	0.40	*<0.01*	0.47
Density	0.81	0.22	0.30

[a]Numbers in italics were significantly different at the $P = 0.05$ level.

Table 4—Sensory means for the main effect "slip" (harvest maturity) in fresh-cut cantaloupes prepared from 4 distinct maturities

	Maturity at harvest (slip)			
	¼-	½-	¾-	full
Fruity/melon	2.8a[a]	3.1a	3.1a	3.0a
Cucurbit	1.2a	1.0a	0.9a	0.9a
Sweet aromatic	1.1b	1.4a	1.4a	1.2ab
Water-like	0.5a	0.5a	0.6a	0.5a
Musty	0.3a	0.2bc	0.1c	0.3ab
Chemical	0.3a	0.3a	0.2a	0.5a
Sweet taste	3.7b	4.2a	4.4a	4.3a
Surface wetness	7.5b	8.0a	8.2a	7.9a
Hardness	4.6a	4.1b	4.0b	4.1b
Moisture release	4.8c	5.4ab	5.6a	5.3b
Cohesiveness	3.9a	3.8a	3.9a	4.0a
Denseness	4.5a	4.4a	4.5a	4.5a

[a,b,c] = means across rows with similar letters are not significantly different based on least square means comparisons.

Table 5—Main effect treatment means and mean comparisons of storage (4 °C) in fresh-cut cantaloupes prepared from 4 distinct maturities

	Days of storage							
	0	2	5	7	9	12	14	Slope[a]
Fruity/melon	2.9a[b]	3.0a	3.0a	3.0a	3.0a	3.1a	3.0a	–0.025[c]
Cucurbit	1.2a	1.2a	1.2a	0.9a	1.2a	0.5a	0.5a	–0.030 *
Sweet aromatic	1.2a	1.1a	1.5a	1.3a	1.4a	0.9a	1.1a	0.008
Water-like	0.7a	0.5a	0.6a	0.7a	0.7a	0.1a	0.1a	0.002
Musty	0.1c	0.3c	0.1c	0.2c	0.1c	0.5a	0.4ab	0.015
Chemical	0.3a	0.4a	0.3a	0.4a	0.3a	0.3a	0.3a	–0.001
Sweet taste	4.1a	4.2a	4.0a	3.6a	3.9a	5.1a	5.2a	–0.030
Surface wetness	7.4b	7.4b	7.9ab	8.3a	8.0ab	7.8ab	8.3ab	0.061 *
Hardness	5.0a	5.1a	4.2a	3.8a	4.0a	3.5a	3.4a	–0.113 **
Moisture release	5.2a	5.2a	5.5a	5.5a	5.1a	5.3a	5.2a	0.014
Cohesiveness	4.2a	4.2a	3.8b	3.8bc	4.1ab	3.7bc	3.4c	–0.039 *
Denseness	4.6a	4.8a	4.5a	4.3a	4.5a	4.0a	4.1a	–0.023

[a]Linear regression trend analysis for days of storage; * = significantly different from 0 at $P < 0.05$; ** = significantly different from 0 at $P < 0.01$.
[b]a,b,c,d = means across rows with similar letters are not significantly different based on least square means comparisons.
[c]Fruity displayed a significant (F = 4.3; P =.0184; df = 2,54) quadratic trend.

indicating that aldehydes comprised 3.0%, 2.6%, 2.5%, and 1.6% of the total volatiles for ¼ slip, ½ slip, ¾ slip, and full slip, respectively (Beaulieu 2004). In addition, in a preliminary in-house panel, we found that both cucurbit/pumpkin and green attributes decreased steadily as 'Sol Real' cantaloupe fruit developed, and this was highly associated with the level of 15 recovered aldehydes (Beaulieu 2004).

Three texture attributes were affected significantly by the degree of slip (maturity). Surface wetness and moisture release intensities increased significantly with maturity from ¼ to ¾ slip, and especially between ¼ to ½ slip, although both attributes declined slightly in full slip (Table 4). This may correlate with loss of selective permeability in melons with the onset of ripening, as previously described (Lester 1998). Because full slip fruit are approaching senescence, where rapid deterioration occurs, these findings do not seem out of order. Hardness was significantly more intense in ¼ slip than all other maturities (Table 4).

The maturity data indicate there are flavor differences between cantaloupes with different degrees of detachment when harvested at 37 to 38 DAA. The panels discriminated numerous significant sensorial differences between ¼ slip compared with full slip. Yet, trained panelist did not find significant differences between ½-slip and full-slip melons for numerous flavor or texture attributes, based on LS means. Using hedonic scales, untrained tasters found differences between ½ slip and full slip in eastern U.S. green and yellow muskmelons after 2 d storage as whole melons, but not after 8 d storage (Evensen 1983). In that study, scores for the ½-slip melons were low because of lack of melon flavor. The ½-slip melons improved during 8 d of storage as whole melons but never reached the level of full-slip melons. Green full-slip melons maintained the flavor scores during 15 d as whole melons. The yellow full-slip melons did not hold up during storage as well as the green full-slip melons. We found only 2 studies in which numerous panelists were used to discriminate flavor in melons via hedonic appraisals. Twenty-five (minimum) panelists per session appraised rockmelons (Mutton and others 1981), and 18 judges evaluated cantaloupe (Yamaguchi and others 1977). These researchers valued the importance of sensory evaluation in monitoring fruit but did not use detailed flavor and texture descriptors with strict training and definitions for studying the sensory changes that occur during storage (Bett 2002). Furthermore, hedonic panel scores for aroma were poorly correlated with total volatiles and eating quality (Yamaguchi and others 1977). Such phenomena would not be applicable in the aforementioned studies where fruit were assessed through storage as whole melons.

Sensory storage effect—days

Duration of fresh-cut storage at 4 °C (an ideal storage temperature for many fresh-cut fruits) had occasional significant effects on cantaloupe flavor and aroma in this analysis. Cucurbit and water-like flavors remained somewhat constant through 9 d storage then decreased by days 12 and 14, yet not significantly. Musty flavor increased significantly by the end of the 14-d shelf-life (Table 5). Although aldehydes are generally considered secondary volatile compounds (Gardner 1989), mainly associated with green or grassy notes, certain aldehydes isolated from melons have been considered as characteristic flavor compounds (Kemp and others 1974; Schieberle and others 1990). Our results demonstrating significant increases in mustiness, and slight decreases in cucurbit aroma during storage may be associated with the relative balance of S-compounds and aldehydes during storage. Fruity and sweet aromatic had little change through storage, whereas sweet taste decreased slightly through 9 d and then increased thereafter.

Storage of the fresh-cut product affected sensory texture attributes to a much greater extent compared with flavor changes. Hardness and cohesiveness significantly decreased with storage (Table 5). The greatest decrease during storage occurred between days 2 and 5. The decrease in hardness was expected because of cutting and subsequent loss of turgor pressure in the cells. Surface wetness increased with storage, although not significantly. The amount of deformation before rupture, cohesiveness, significantly declined during storage (Table 5). In a previous study with 4 cantaloupe cultivars, we found that cohesiveness remained somewhat constant (such as in 'Sol Real') or increased during storage (Bett-Garber and others 2003). We expected similar results for cohesiveness, however 'Sol Real' in the current study displayed a significant decrease through storage. This might indicate that yearly, cultural, or regional genetic interactions are important.

Fruity flavor had a significant (F = 4.3; P = 0.0184; df = 2,54) quadratic trend during storage (Table 5), which was not affected by maturity (Figure 1). Fruity was less intense on days 0, 2, 12, and 14 than on days 5, 7, and 9. We have observed similar transient increases in various flavor attributes in other fresh-cut fruit studies (Bett and others 2001; Bett-Garber and others 2003). Such transient increases are difficult to rationalize because they are independent of maturity and have occurred in fresh-cut apple and numerous cantaloupe cultivars.

Fresh-cut fruit sensory interaction effects—maturity × storage (days)

No significant sensory main interaction effects between maturity and days storage were determined based on the ANOVA (Table 3). Some significant differences were found in a preliminary analysis of variance treating days of storage as classes (df = 6) as individual treatment means (Table 5). In another analysis, days of storage were treated as trends (df = 1 when linear; df = 2 when quadratic), as a quantitative treatment. If there was a trend in the treatment means, this analysis has more power (ability to find a difference if it exist) for evaluating the effect of storage days. Results of the trend analysis indicated notable changes in sensory attributes over storage day because of the maturity at harvest (Table 5, slope column). For example, the interaction mean slope estimate for cucurbit indicated that the linear slope in ¼-slip cubes were significantly different compared with all other maturities (Figure 2). Cucurbit flavor was more intense in the ¼-slip melons at day 0 and day 2 but decreased after 5 d of storage to be comparable to the ½, ¾, and full slip. An almost identical linear trend in the slope estimates for hardness was also found in ¼-slip cubes. Hardness was significantly more intense (harder) in ¼-slip cubes during 0 to 9 d of storage compared with all other maturities (Figure 3). Yet, after 12 and 14 d of storage, ¼-slip cubes were comparable in intensity to ½, ¾, and full slip.

Sweet aromatic flavor also displayed a quadratic trend, but the trend was markedly different among maturity groups. The trends for ½-, ¾-, and full-slip melons were not significantly different; however, cubes prepared from ¼-slip melons were different from the other maturities (Figure 4). In ¼-slip cubes, sweet aromatic intensity was low on days 0 and 2, increased on days 5, 7, and 9, and then decreased. After day 5, the ¼-slip melon attributes were comparable to the intensities of attributes in other maturities. By days 12 and 14, these flavors were less intense in ¼-slip melons than the ½-, ¾- and full-slip melons. It is unclear why a logical sequence of relationships was not followed with regard to the trend lines being similar for ¼-slip and ¾-slip compared with ½-slip and full-slip fruit.

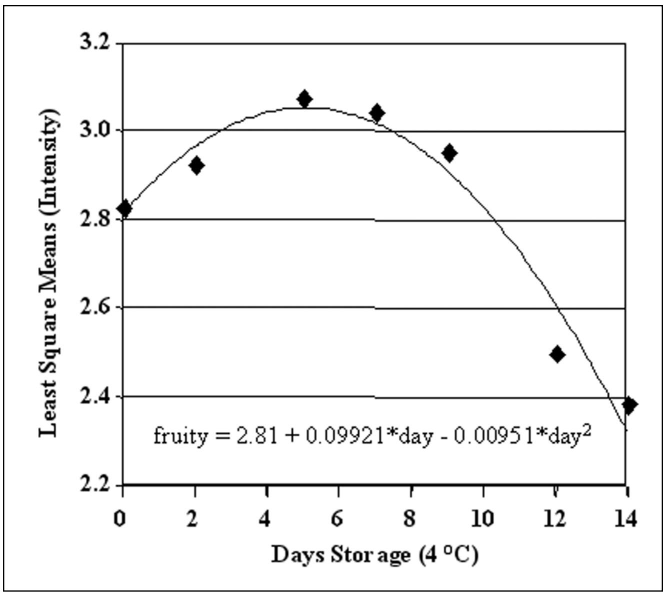

Figure 1—Quadratic trend analysis of fresh-cut cantaloupe fruity melon flavor changes during storage (4 °C) across all maturities. Symbols are the combined experimental least square means, and the line represents the fitted quadratic model.

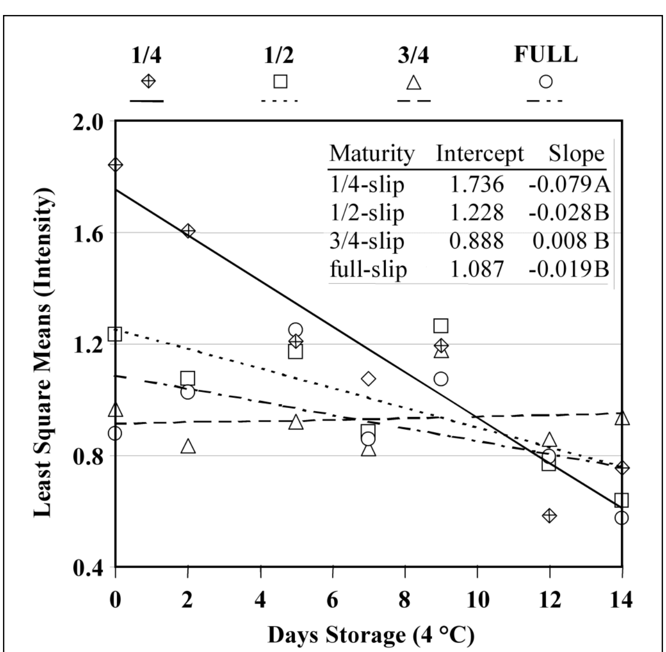

Figure 2—Linear trend analysis of fresh-cut cantaloupe cucurbit flavor changes during storage (4 °C) among maturity. Symbols are the experimental least square means, and lines represent the fitted linear models. A and B represent significant slope differences in the trends at $P \leq 0.05$.

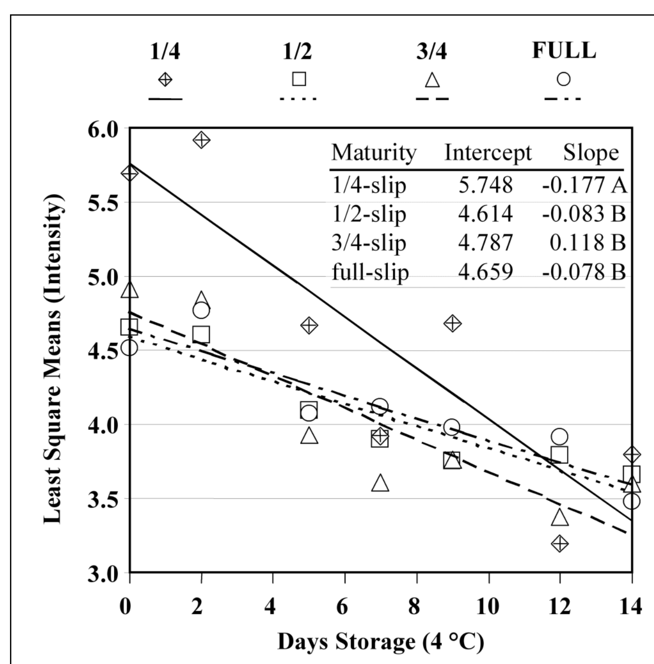

Figure 3—Linear trend analysis of fresh-cut cantaloupe hardness texture changes during storage (4 °C) among maturity. Symbols are the experimental least square means, and lines represent the fitted linear models. A and B represent significant slope differences in the trends at $P \leq 0.05$.

Table 6—The combined, aggregate gas chromatography/mass spectrometry average of integrated ion responses for 2 flavor-important volatile classes[a] and their maturity related changes through storage as fresh-cut cantaloupe

	0 d		5 d		9 d		14 d	
Maturity	Average[b]	SE	Average	SE	Average	SE	Average	SE
Non-acetate esters (17 compounds)								
Full slip	27,424,995	11,646,713	61,485,695	20,523,980	52,524,733	22,146,617	36,201,833	633,747
¾ slip	17,376,650	6,797,497	47,691,235	8,749,539	48,469,871	8,598,304	33,089,016	546,661
½ slip	17,229,405	2,214,041	47,242,288	1,615,467	39,128,258	3,193,875	25,442,590	542,040
¼ slip	18,043,671	8,045,376	28,069,730	6,772,591	32,682,583	5,886,220	17,800,524	514,856
Acetates (11 compounds)								
Full slip	41,869,551	12,774,619	42,221,230	17,153,379	35,777,853	17,103,962	14,013,565	194,770
¾ slip	37,992,249	7,151,174	42,713,402	11,923,727	36,733,009	11,999,178	15,328,246	458,585
½ slip	34,982,011	2,069,322	38,293,587	9,128,350	30,499,160	9,951,447	10,101,230	78,261
¼ slip	29,112,194	3,652,421	22,683,851	2,884,728	23,606,889	4,256,730	8,820,829	435,768

[a]Compounds comprising the classes are listed according to the "Materials and Methods" section.
[b]Averages are the resulting summation of the integrated target ion response for all compounds comprising the class over 2 y. There were 3 discrete replicates in each year, hence, $n = 6$.

Sweet taste was consistently less intense in the ¼-slip melons than the ¼-, ¾- and full-slip melons during the entire storage period but not significantly. Fruity melon and sweet taste tended to increase through storage in most maturities. These results were unexpected because cantaloupes have no starch reserves to catabolically yield additional sugars during storage (Hubbard and others 1990). However, there was a gradual curvilinear significant increase in the relative percentage of non-acetate esters through storage, for all maturities (Beaulieu 2004) (Table 6), and several of these compounds have sweet/fruity descriptors (Beaulieu, unpublished data). Simultaneously, acetates, including benzyl acetate, significantly decreased during storage (Beaulieu 2004) (Table 6). Acetates are often considered the most important class of volatiles, imparting fruits their unique and characteristic aroma and flavor, especially in Galia- or Charentais-type melon fruit (Bauchot and others 1998; Shalit and others 2001). The levels of acetate esters increase with the ripening of the fruit (Table 6), then decrease as the fruit progress to the overripe stage (Horvat and Senter 1987). It is therefore likely that the perceived fruity/melon increase was associated with an ester imbalance: an overall increase in normally unimportant non-acetate esters with dominant sweet/fruity notes overpowers the specifically important fruity notes of acetates, as they declined.

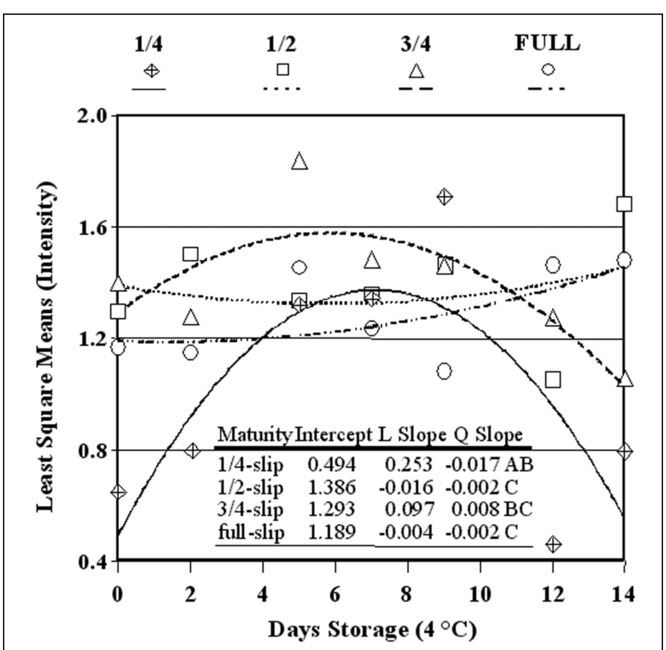

Figure 4—Linear and quadratic trend analysis of fresh-cut cantaloupe sweet aromatic flavor changes during storage (4 °C) among maturity. Symbols are the experimental least square means, and lines represent the fitted linear models. A, B, and C represent significant slope differences in the trends at $P \leq 0.05$.

Instrumental texture analysis

The slope of the force deformation curve followed a decreasing linear trend that was maturity dependent. The magnitude of the slope decreased with increasing maturity (¼ slip = –0.299 to full slip = –0.036). This is an indication that the effect of storage time decreased as maturity increased, as established in the slope estimates for ¾ slip and full slip, which were not statistically different from 0 ($P = 0.0993$ and 0.1614, respectively). The mean slope gradient for ¼ slip (3.41) compared with ½ slip (1.85), ¾ slip (1.40), and full slip (1.29) were statistically different ($P = 0.05$) on day 0 (Figure 5). However, by day 9, the mean slopes for the 4 maturity levels were not statistically different ($P > 0.05$). This measure of elasticity has been highly related to product firmness (Ang and others 1960), crispness, and hardness (Abbott and others 1984). Subsequently, cubes prepared from ¼-slip fruit were statistically firmer (harder) and

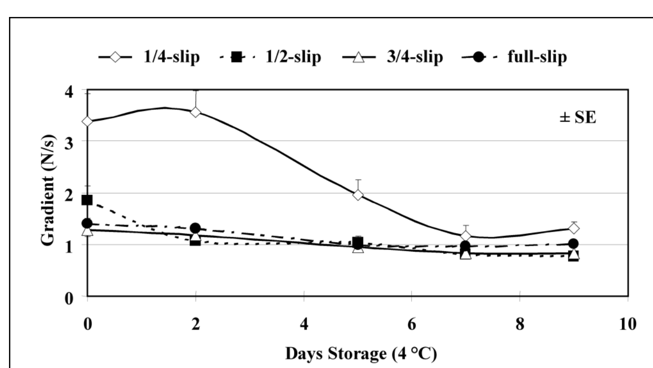

Figure 5—Slope (Newton/s) until the 1st bioyield point on the force deformation curves for 1 cm³ fresh-cut cantaloupe cubes prepared from fruit at 4 distinct maturities. SE = standard error bars about the means ($n = 10$).

Table 7—Correlation between instrumental texture means (maturity × day) data compared with sensory texture means data

	Panelist texture attributes				
Instrumental texture	Wetness	Hardness	Moisture release	Cohesiveness	Denseness
Bioyield force	–0.694 (<0.01)	0.787 (<0.01)	–0.499 (0.02)	0.214 (0.35)	0.455 (0.04)
Bioyield area	–0.678 (< 0.01)	0.779 (< 0.01)	–0.516 (0.02)	0.197 (0.41)	0.442 (0.05)
Slope	–0.719 (<0.01)	0.792 (<0.01)	–0.447 (0.04)	0.283 (0.21)	0.462 (0.03)
Total area	–0.719 (<0.01)	0.787 (<0.01)	–0.454 (0.04)	0.261 (0.25)	0.444 (0.04)
Young's modulus	–0.715 (<0.01)	0.628 (<0.01)	–0.274 (0.24)	0.517 (0.02)	0.275 (0.24)

[a]Analyses (year 1 only) are presented as the coefficient of correlation, *r*, and the corresponding test of the null hypothesis (Ho: $r = 0$) indicated parenthetically (*P* value).

retained crispness longer in storage compared with the other maturities. Panelists discriminated these significant hardness differences in ¼-slip cubes on day 0 and through 2 d of storage (Table 3 and 4). Overall, hardness was positively correlated with all 5 instrumental measures of texture (Table 7). Crispness and hardness are desirable in fruits such as apple, but high measures for these attributes in ¼-slip cantaloupe are likely unfavorable.

The force at the 1st bioyield (firmness) followed a decreasing linear trend that was maturity dependent. The magnitude of the slope decreased with maturity (¼ slip = –2.615 to overripe = –0.658). This again indicates that the effect of storage time decreased as maturity increased. This was reflected in the slope estimates for ¾ slip and full slip, which were not statistically different from 0 ($P = 0.1068$ and 0.3145, respectively). The mean firmness for ¼ slip (23.80) compared with ½ slip (10.88), ¾ slip (6.97), and full slip (6.92), were statistically different ($P = 0.05$) on day 0, and throughout storage (Figure 6). On day 9, mean firmness for ¼ slip (9.58) compared with ½ slip (3.25), ¾ slip (3.37), and full slip (4.81) were still statistically different. The maximum force at the bioyield has been defined as hardness by numerous authors (Meullenet and others 1998). Bioyield force was significantly correlated with trained sensory evaluations for hardness and denseness (Table 7). On the other hand, both wetness and moisture release displayed an inverse relationship with all parameters measured for texture instrumentally, and these parameters were

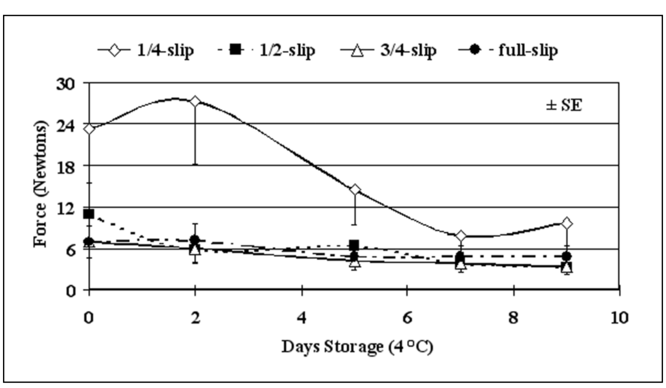

Figure 6—Force (Newtons) at the 1st bioyield point on the force deformation curves for 1 cm³ fresh-cut cantaloupe cubes prepared from fruit at 4 distinct maturities. SE = standard error bars about the means ($n = 10$).

generally well correlated (Table 7). Most instrumental texture trends were highly conserved for the ¼-slip fruit.

Conclusions

When evaluated under red light conditions, ½-, ¾- and full-slip cantaloupe had comparable sensory performance as fresh-cut product at optimum temperature of 4 °C. Correspondingly, fruity and sweet aromatic flavor were significantly less intense in ¼-slip cubes compared with ½- and ¾-slip maturities. Sweet taste was consistently significantly less intense in ¼-slip cubes during the entire storage period (14 d). Hardness was more intense (harder) in ¼-slip cubes during 0 to 9 d. This trend was almost equaled with instrumental texture determinations. The slope of the force deformation curve and force at the 1st bioyield point indicated clearly that ¼-slip harvested fruit were firmer than the other 3 maturities, and these cubes retained the most firmness through at least 5 d storage. Meanwhile, ¼-slip cubes were significantly less intense in surface wetness and moisture release on day 0 and across storage. Cubes prepared form ¼-slip fruit were not mature enough to optimize sensory attributes, as sweet aromatic and sweet flavors were less intense, texture was firmer, and there was less moisture release (less juicy). In terms of desirable sensory attributes, it appears that fresh-cut cantaloupe cubes should be prepared with fruit harvested ≥ ½ slip. However, based on a detailed volatile analysis (Beaulieu 2004), it is likely that ½-slip cubes do not have sufficient relative concentrations of most volatile compounds considered flavor-important in muskmelons, compared with ¾ slip and full slip. Careful judgment should therefore be exercised when attempting to maximize shelf-life by cutting less mature fruit and during off-season production with less mature fruits. Even though this study indicates a clear sensory separation exists between ¼-slip fruit compared with more ripe fruit, the relative flavor-important acetate and ester concentrations dramatically increased with increasing harvest maturity.

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