



# Volatile and quality changes in fresh-cut mangos prepared from firm-ripe and soft-ripe fruit, stored in clamshell containers and passive MAP

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## Abstract

A study was performed to assess volatile and quality changes in stored fresh-cut mangos prepared from “firm-ripe” (FR) and “soft-ripe” (SR) fruit, and to assess what effect passive modified atmosphere packaging (MAP) may have on cut fruit physiology, overall quality and volatile retention or loss. Florida-grown ‘Keitt’ and ‘Palmer’ mangos were used, without heat-treatment. Subjective appraisals of fresh-cut mangos based on aroma and cut edge or tissue damage indicated that most SR cubes were unmarketable by day 7 at 4 °C. Both varieties stored in MAP at 4 °C had almost identical O<sub>2</sub> consumption, which was independent of ripeness. Percent CO<sub>2</sub> and O<sub>2</sub> data for cubes stored in passive MAP indicates that the system was inadequate to prevent potential anaerobic respiration after 7 days storage. A significant three-way interaction (container × ripeness × day) was observed for L\* (lightness) between stored cubes prepared from FR versus SR fruit of both varieties. There was a linear L\* decrease for SR ‘Keitt’ cubes stored in clamshell containers. δ-3-Carene was the dominant terpene in both varieties in all treatments throughout most of the study, and FR cubes had statistically higher levels of seven terpenes compared with the respective SR treatments. Most terpenes in FR and SR cubes stored in both package types displayed a transient increase, occurring on day 4 or 7, followed by a decline.

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## 1. Introduction

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. Nonetheless, fresh-cut fruit sales have lagged behind their vegetable counterparts for numerous logistical, physiological

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and biochemical reasons. Fresh-cut fruit sales have grown in a linear manner, at roughly \$1 billion per year (Anonymous, 1999a), due largely to increased regional production and distribution. Fresh-cut sales of \$8.8 billion accounted for roughly 10% of the total US fresh vegetable and fruit market in 1998, and recent predictions indicate that sales may reach \$14 billion by 2003 (Anonymous, 1999b). Per capita mango consumption in the US has increased 3-fold since 1990 (Pollack, 2000). As both fresh-cuts and mango consumption increase, there appears to be an incentive to improve the intrinsic qualities of fresh-cut mango products. However, limited information has been published regarding fresh-cut mango physiology, and less information exists regarding fresh-cut fruit flavor quality (Beaulieu and Baldwin, 2002).

Fresh-cut processing increases respiration rates and causes major tissue disruption as enzymes and substrates become mixed. Processing increases wound-induced ethylene, and surface area per unit volume, which may enhance microbial attack and accelerate water loss (Watada and Qi, 1999; Wiley, 1994). These physiological changes may be accompanied by browning, decay, increasing rate of vitamin loss, rapid softening, color loss and a reduced storage life (Watada et al., 1990). Increased water activity and mixing of intracellular and intercellular enzymes and substrates may also contribute to flavor and texture changes/loss during and after processing.

Fresh-cut mangos could be made available year round. However, products made from imports would dominate the US market because domestic production has a very narrow harvest window, which has declined markedly since the early 1990s (Pollack, 2000). Therefore, it is important to view changes in fresh-cut mango quality with regard to initial fruit maturity and source. This is especially true because significant flavor and aroma differences have been reported for mature-green (MG) versus ripe mangos (Bender et al., 2000a; Engel and Tressl, 1983; Gholap and Bandyopadhyay, 1977), and for different mango varieties (Ackerman and Torline, 1984; MacLeod and Snyder, 1985; Narain et al., 1998). Imported fruit are harvested MG and receive a hot water or steam quarantine treatment before entry to the US.

Numerous factors may limit the quality of a fresh-cut product that could be produced year-round from imported mango fruit. Subsequently, to establish baseline aroma and physiological information, we investigated differences in domestically grown Florida mangos that were commercially harvested, received no heat treatment, and were processed at different maturities then stored in clamshell containers or modified atmosphere packaging (MAP).

## 2. Materials and methods

### 2.1. Fruit source and processing

‘Keitt’ and ‘Palmer’ mangos (*Mangifera indica* L.) were commercially harvested near Homestead, Florida at the ripe commercial stage (color break, shoulders developed and/or shoulder bloom) and shipped, without steam or hot-water quarantine treatment, the same week to the Southern Regional Research Center lab. Fruit were processed upon receipt at the firm-ripe (FR) stage (Table 1), then at the soft-ripe (SR) stage 4 days later after 4 h exposure to 550  $\mu\text{l l}^{-1}$  static ethylene and subsequent ripening at room temperature.

Fruit were washed in cold running tap water followed by submersion into 100  $\mu\text{l l}^{-1}$  sodium hypochlorite (pH 6.5–7) at 4 °C for 3–5 min. Afterwards, fruit were completely peeled with sharp paring knives, 2–3 mm into the subepidermal tissue to remove all visible veins and eliminate potential browning (Limbanen et al., 1998). Stem scar ends were completely removed and peeled fruit submerged again for up to 5 min, in fresh chlorinated 4 °C water. Fruit were cut in a filet-like fashion, following the flat side of the seeds and cubes were prepared averaging 2.5 × 2.5 cm. Cubes (175 g) from a representative pool of at least five fruit per variety were placed immediately into clamshell Juice Catcher (JC) containers (Winkler Forming, Carrollton, TX, SRW-24) or 250 g into MAP trays (Green-Tek, Inc., Egerton, WI, polypropylene 5002).

Table 1

Initial quality characteristics for whole fruit (firmness) and prepared fresh-cut mango cubes (all other parameters)

Parameter	Firm-ripe (FR)		Soft-ripe (SR)	
	'Keitt'	'Palmer'	'Keitt'	'Palmer'
Firmness <sup>a</sup> (N)	91.5±28.2	85.5±32.2	29.4±9.5	26.7±7.6
°Brix (%)	8.9±0.3	10.1±0.3	12.5±0.2	13.9±0.3
Respiration (nmol kg s <sup>-1</sup> )	639±38	587±19	–	–
<i>Hunter color</i>				
L*	76.93±3.79	76.48±4.66	70.27±4.55	67.80±3.60
a*	0.28±3.75	0.41±4.26	3.76±4.71	6.27±4.71
b*	58.91±5.90	62.62±7.60	69.96±4.35	72.64±4.19
Subjective color	Pale yellow to pale yellow/pale orange flesh		Yellow/orange to pale orange/orange flesh	

<sup>a</sup> Firmness (hand-held McCormick, FT327, Italy, 11.3 mm probe, skin removed) of ten whole fruit per variety, per ripeness (±std). All other parameters presented are according to the Section 2 (±std).

## 2.2. MAP and refrigerated storage

Polypropylene MAP trays were over-wrapped with 61 µm HB-60 Toplex film (Green-Tek). The MAP machine (Koch Kats 100 Basic V/G [Ilpra Foodpack Basic V/G], Kansas City, MO) was operated with the following specifications: a vacuum was drawn (–40 kPa), containers were flushed with purified breathable air (21 kPa O<sub>2</sub> and 0.03 kPa CO<sub>2</sub>), and sealed for 7 s at atmospheric pressure with a seal temperature of 150 °C. Packaged fresh-cut cubes were held at 4 °C and stored 0, 4, 7, 11 and 14 days. Chilling injury is a concern in whole mango fruit (Saucedo et al., 1977), but was apparently not an issue in fresh-cut mangos stored at 5 °C (Limbanyen et al., 1998; Rattanapanone et al., 2001). Four replicate containers were used for all treatments on each storage day.

## 2.3. Physiological measurements and respiration

A subjective hedonic quality criterion similar to Wright and Kader (1997) was developed for fresh-cut mango to assess specific attributes and overall quality throughout storage (Table 2). Odd whole numbers were sound judgments whereas even numbers were used for borderline decisions. Four trained judges independently performed the subjective assessment and results were averaged. Color measurements (L\*, a\*, b\*) were recorded

with a Hunter color meter (DP-9000, Reston, VA) calibrated against both white and black color tiles. Color readings were taken from sides of cubes that were sliced cleanly, not the soft, stringy side adjacent to the seed nor the skin-peeled side ( $n = \sim 80$  FR and  $n = \sim 75$  SR). Soluble solids (°Brix%, Atago, Japan, PR101) and pH were measured in extracted juice samples.

Upon receipt, eight to ten whole fruit per variety were sealed in large vessels (~19 l) for static (3–4 h) CO<sub>2</sub> readings (day 0, FR lot). CO<sub>2</sub> was measured via 6 min runs by injection into a Varian 3800 (Walnut Creek, CA) gas chromatograph (GC) equipped with a 6.1 m × 3.2 mm stainless steel Hayesep N column (80/100) at 50 °C with a thermal conductivity detector at 200 °C. A Mocon Pac Check 650 (Minneapolis, MN) was also used to measure percentage CO<sub>2</sub> and O<sub>2</sub> in the MAP's, as well as CO<sub>2</sub> from whole fruit sealed in large vessels and cubes removed from JC containers that were subsequently held static for 3–4 h in 500-ml jars.

## 2.4. GC–MS volatile sample preparation

Volatile samples were prepared from fresh-cut cubes for each treatment on each storage day ( $n = 4$ ). Certain isolation procedures have been shown to produce artifact compounds in mango (Bartley and Schwede, 1987; Sakho et al., 1985). Therefore, similar tissue homogenization and solid phase

Table 2  
Subjective descriptors for fresh-cut mango

Quality attributes	Subjective score <sup>a</sup>				
	9	7	5 <sup>b</sup>	3	1
Overall color (loss of yellow or to orange color)	Very fresh and “normal” appearing (per variety). “Tree-ripe”	Slightly visible loss of bright orange color, or pale yellow/orange	Visibly more pale color and slightly pale flesh that may be noticed by consumer	Obvious pale or whitish discoloration	Severely pale “washed” looking
Edge or tissue damage (also vein browning)	None, very fresh and normal appearing; sharp knives were used, no visible veins	Slightly visible loss of orange color but, not actually soggy or watery looking; small% visible veins browning	Edges slightly soggy or water-soaked with darker color, or darkening of veins; slight texture loss	Obvious edge damage, like compression bruising; veins markedly browning; “goosey” appearance	Severe edge damage with obvious water-soaking or associated soggy appearance; brown veins
Spoilage	None	Minor; perhaps increased spore counts, but only via lab testing	Noticeable by trained person but most consumers may not observe	Slimy surfaces on some pieces with a slightly “goosey” appearance	Obvious mold, or slimy surfaces and “goosey” pieces (bacterial)
Aroma Smell	Normal, characteristic, fresh mango (peachy, coconut, almond, caramel)	Normal to perhaps slightly “flat” or “off” to a trained person (piney, green mango/woody)	Detectable “off odor” ( <i>i.e.</i> when open package, but dissipates) still edible	Off-odors moderate (slightly anaerobic), becoming offensive	Off-odors strong. The product is “fermented-like” (musty)
Desiccation	None, very fresh with a wet gleam	Slightly visible water loss on edges, but only to a trained person	Progressive drying on cube edges, often undetected by consumers	Little to no surface gleam, slightly dehydrated surfaces	Severe, tissue drying, similar to white blush on sliced carrots

<sup>a</sup> Generally: 9, excellent; 7, very good; 5, limit, good; 3, fair, absolute limit for household use with trimming and/or loss; 1, poor, inedible.

<sup>b</sup> Five is the minimum subjective score (limit) for marketing any product.

microextraction (SPME) headspace GC–MS methods were used, as previously published (Beaulieu and Grimm, 2001). Briefly, tissue was juiced (~15 s) into a slurry with a Braun MP80 Juicer (Germany), 3-ml slurry (without foam) was immediately pipetted into 10-ml glass vials containing 1.1 g NaCl that were sealed with a steel crimp cap fitted with a Teflon/silicon septum, placed on a Combi-Pal Autosampler (Leap Technologies, Carrboro, NC) cooling rack at 4 °C, and analyzed with automated SPME within 8 h. Little to no oxidative headspace volatile products have been observed in numerous Florida-grown mango cultivars (Malundo et al., 1997) and in our preliminary studies (data not shown). Furthermore, attempts to suppress potential oxidation during blending via CaCl<sub>2</sub> caused gelling, which decreased terpene volatile release into the headspace (Malundo et al., 1997). Therefore, no enzyme inhibitor or antioxidant was included during homogenization. NaCl was added to homogenized slurries as a “salting out” technique used for maximizing volatile partitioning into the headspace phase over the liquid phase during equilibration and SPME adsorption.

### 2.5. Headspace SPME GC–MS analysis and data processing

Sample vials were equilibrated 10 min via oscillation in a 40 °C chamber, then a 1-cm 100 µm PDMS SPME fiber was inserted into the headspace for 12.5 min at 40 °C. Vials were continuously swirled during SPME adsorption with an agitation speed of 100 min<sup>-1</sup>. Fibers were desorbed at 250 °C for 1 min in the injection port of an HP6890/5973 GC–MS (Hewlett Packard, Palo Alto, CA) with a DB-5 (crosslinked 5% phenyl methyl silicone, J&W Scientific, Folsom, CA) column (30 m, 0.25 mm I.D., 25 µm film thickness) for 32-min runs. The injection port was operated in splitless mode and subjected to a pressure of 25 kPa of ultrahigh purity helium (99.9995%) for the first minute, and then set at a constant velocity of 40 cm s<sup>-1</sup> (split mode) for the remainder of the GC run. The GC inlet was cryofocussed (–60 °C) as compounds were desorbed (1 min) from the SPME fiber. In pilot

studies, we utilized GC–MS methods similar to those previously reported (Ibáñez et al., 1998; Malundo et al., 1997), but ultimately used a faster temperature rate program to better separate terpenes. The initial oven temperature was 50 °C, held 1 min, ramped 5 °C min<sup>-1</sup> to 140 °C then 10 °C min<sup>-1</sup> to 250 °C and held 2 min. The HP5973 quadrupole mass spectrometer was operated in the electron ionization mode at 70 eV, a source temperature of 200 °C, with a continuous scan from *m/z* 33 to 300.

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, NY). Compounds were identified by library search and the identity of all compounds reported was confirmed with standards. There was marked variability in compound recovery between maturities and varieties over storage. Therefore, integrated area counts based on selected unique qualifying target ions for specified compounds were presented (Table 3). Because δ-3-carene was usually the dominant compound recovered in most samples, we also evaluated the data from the total ion chromatograms on a relative percentage basis. The ion count of δ-3-carene was divided by the total ion count of all integrated compounds, then expressed as a relative percentage. Hence, the reported volatile data are semi-quantitative. In some instances, when a replicate for a given compound had a markedly different quantified ion count and ion ratio, it was treated as an outlying point, and removed from the data set.

### 2.6. Statistical design and analysis

The experiment was set up as a completely randomized design with a four-way treatment structure (2V × 2R × 2C × 4D): two varieties (V), two ripeness levels (R), two container types (C) and 5 days (D). Color, subjective, physiological and volatile data were analyzed as a completely randomized design with a four-way treatment structure as separate ANOVA's per factor. Respiration and percent CO<sub>2</sub> and O<sub>2</sub> data were analyzed as a completely randomized design with a three-way treatment structure (V × R × D) as separate ANOVA's per factor. Tukey's multiple

Table 3

Main effect means (abundance, based on target ion response) for ten volatile compounds recovered via solid phase microextraction, GC–MS in stored fresh-cut mango cubes

Treatment	ethanol	Ethyl acetate	ethyl butanoate	alpha-pinene	beta-myrcene	delta-3-carene	alpha-terpinene	limonene	alpha-terpinolene	alpha-humulene	
Variety	K	878,308	186,255	133,014	255,511	520,624	3,500,576	100,803	475,416	102,979	488,732
	P	1,393,542	243,595	184,353	85,821	144,302	1,453,226	28,182	158,490	31,796	188,080
Ripeness	FR	906,033	66,933	52,440	304,941	608,697	4,309,494	118,319	567,741	121,381	641,255
	SR	1,365,818	362,917	264,927	36,391	56,230	644,307	10,766	66,164	13,393	35,557
Contain	JC	88,227	64,489	10,819	193,656	385,866	2,488,397	76,001	353,540	77,548	434,822
	MAP	2,183,623	365,360	306,547	147,676	279,061	2,465,404	52,985	280,365	57,227	241,990
Days	0	124,260 <sup>A</sup>	45,936 <sup>A</sup>	114,07 <sup>A</sup>	310,271	603,190	3,740,408	118,142	539,746	116,832	667,712
	4	88,571 <sup>A</sup>	43,487 <sup>A</sup>	26,982 <sup>A</sup>	182,828	371,203	3,144,526	76,603	370,003	78,424	216,707
	7	1,594,100 <sup>AB</sup>	292,362 <sup>B</sup>	164,968 <sup>B</sup>	136,223	260,490	2,116,444	47,128	256,146	54,018	360,685
	11	2,736,769 <sup>B</sup>	477,914 <sup>B</sup>	431,376 <sup>C</sup>	53,341	94,969	906,225	16,098	101,916	20,275	108,519

Daily means separated by different letters within columns, are significantly different ( $P < 0.05$ ) according to Tukey's multiple comparison procedure with an experiment-wise error rate at 0.05. Volatile means per factor in shaded cells are statistically different at the  $P$ -value  $\leq 0.05$ . K, 'Keitt'; P, 'Palmer'; FR, firm-ripe; SR, soft-ripe; JC, juice catcher; MAP, modified atmosphere package.

comparison procedure was employed to evaluate main 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.

### 3. Results and discussion

#### 3.1. Subjective appraisals

Cumulative subjective averages (sum of "off color", "edge or tissue damage", "spoilage", "aroma/smell" and "desiccation") indicate clearly that fruit processed FR (Fig. 1A) had lower initial scores compared with SR fruit (Fig. 1B). This was mainly attributed to the lack of characteristic orange or deep orange flesh color (see below color data) and due somewhat to the lack of characteristic ripe odors in FR cubes (Fig. 2A). Color, edge or tissue damage, spoilage, aroma, desiccation, and the cumulative averages were significantly different for variety, container and storage time

main effects (all  $P = 0.001$ ), as well as the variety  $\times$  container  $\times$  days interaction ( $P = 0.001$ ). The  $V \times C \times D$  interaction means displayed a decrease from 0 to 14 days, but within each day, there were no variety or container trends. FR cubes had a gradual, almost linear, drop off in cumulative subjective quality through 14 days storage (Fig. 1), but they became unmarketable by 11 days due to lack of aroma (Fig. 2A) and desiccation (Fig. 2B). Aroma increased in all FR treatments on day 4, presumably as tissue ripened, then gradually tapered off through storage. On the other hand, fruit processed at the SR stage had better initial cumulative quality due mainly to superior color (Fig. 1B) and higher initial aroma/smell (Fig. 2A), which decreased rapidly. With strict adherence to the subjective criteria (Table 2), a single judge can reliably assess when product becomes unmarketable (score = 5) for given attributes. Although cumulative subjective averages indicated that SR cubes were still marketable through 11 days (Fig. 1A), individual subjective attributes such as aroma (Fig. 2C) and edge or



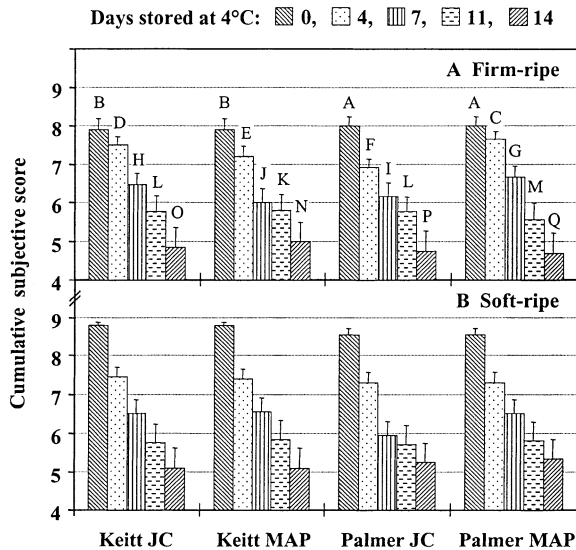


Fig. 1. Cumulative subjective scores for firm-ripe (FR) (A) and soft-ripe (SR) (B) fresh-cut 'Keitt' and 'Palmer' mango cubes stored at 4 °C in modified atmosphere packages (MAP) or JC clam shell containers ( $n = 4$ ). Error bars indicate the standard error (S.E.) about the population mean ( $n = 20$ ). Interaction means ( $V \times C \times D$ ) that were significantly different according to Tukey's multiple comparison procedure (0.005 error rate) are indicated in panel A ( $n = 4 \pm \text{std}$ ).

tissue damage (Fig. 2D) indicated that most SR cubes were unmarketable by 7 days. No apparent spoilage or desiccation in SR cubes skewed the overall cumulative subjective average. The most critical factor reducing SR cube quality was edge or tissue damage, resulting in poor texture and mushy tissue, followed by aroma loss and general discoloration. Visible brown veins were only noted in FR fruit during preparation and all veins were carefully removed. Throughout storage at 4 °C, no visible chilling-injury symptoms were observed in any fresh-cut treatments.

### 3.2. Respiration and MAP gas analysis

A representative sub-sample of whole FR fruit indicated the CO<sub>2</sub> production was  $587 \pm 19$  and  $639 \pm 38$  nmol kg s<sup>-1</sup> for 'Palmer' and 'Keitt', respectively, and fresh-cut 'Keitt' ( $365.747$  nmol kg<sup>-1</sup> s<sup>-1</sup>) and 'Palmer' ( $691.182$  nmol kg<sup>-1</sup> s<sup>-1</sup>) were statistically different (Std. Error =  $83.2$  nmol kg<sup>-1</sup> s<sup>-1</sup>). Whole fruit CO<sub>2</sub> production fell within

the range of fresh-cut respiration rates for processed cubes (Fig. 3), but 'Palmer' FR cubes were markedly higher on day 0. This may indicate a variety-dependent wound-induced respiratory surge exists in fresh-cuts prepared from FR mangos. With one exception (SR 'Palmer' from 7 to 11 days), respiration rates decreased from 0 through 4 days, then slightly increased or remained relatively constant through 11 days for both FR and SR cubes held in clam shell containers. There were no statistically significant differences between the variety  $\times$  ripeness means within days 4 and 7. By day 11, 'Palmer'/SR ( $814.043$  nmol kg<sup>-1</sup> s<sup>-1</sup>) was statistically different from the other three means. However, the SR 'Palmer' containers on day 11 may have had bacterial-associated CO<sub>2</sub> since two readings were very high ( $1079.4 \pm 17.1$  nmol kg s<sup>-1</sup>) whereas the other two values were much lower ( $553.1 \pm 12.4$  nmol kg s<sup>-1</sup>), similar to the other three treatment levels. Inconsistent respiration data for various fresh-cut mangos appear in the literature. Contrary to our findings, the steady state CO<sub>2</sub> rate increased slightly ( $72$ – $120$  nmol kg s<sup>-1</sup>) from 0 to 5 days in 'Tommy Atkins' cubes prepared from imported, heat-treated fruit ( $13$ – $27$  N) that were held in air at 5 and 10 °C (Rattanapanone et al., 2001). On the other hand, in non-heat-treated 'Kent' slices (that were dipped into a solution containing CaCl<sub>2</sub>, citric acid, H<sub>2</sub>O<sub>2</sub> and sodium benzoate), respiration markedly decreased in storage at 5 or 13 °C through 14 or 9 days, respectively (Tovar et al., 2001b). It is, therefore, difficult to determine if respiration patterns in fresh-cut mangos are due to variety, heat-treatment, browning inhibition treatments or MAP.

'Keitt' and 'Palmer' cubes stored in passive MAP at 4 °C had almost identical O<sub>2</sub> consumption rates, which were independent of ripeness (Fig. 4). After 4 days storage, packages had roughly 2.3–3.7 kPa O<sub>2</sub> remaining, and O<sub>2</sub> dropped rapidly and approached apparent anaerobic levels (0.1–0.4 kPa) by day 7. Only day 0 and 4 means were significantly different from each other, and from days 7 and 11 (Fig. 4A). For CO<sub>2</sub>, ripeness and day main effects and the  $V \times D$  and  $R \times D$  interaction effects were all statistically significant. All variety  $\times$  day means were statistically different

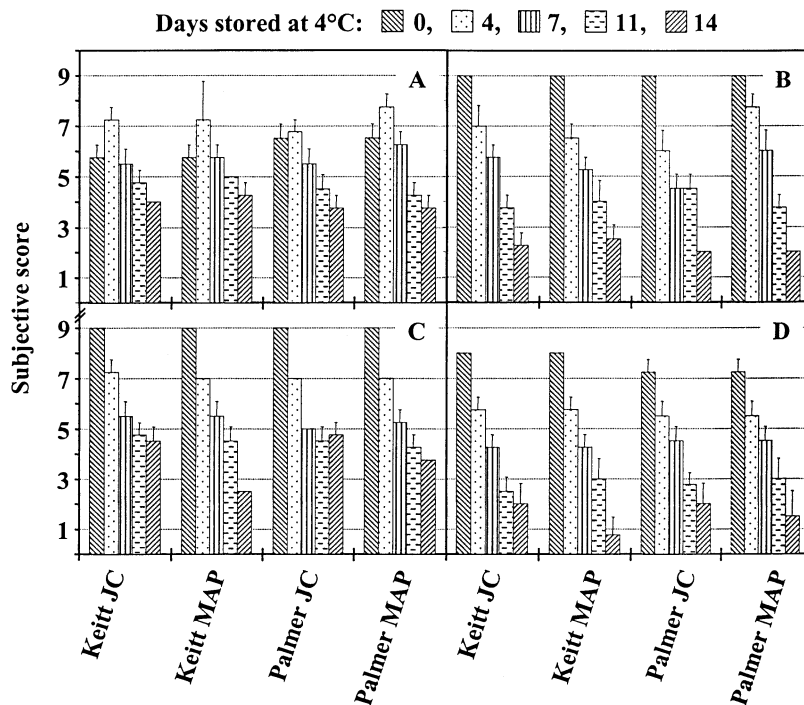


Fig. 2. Subjective scores for firm-ripe (FR) aroma/smell (A) and desiccation (B), and soft-ripe (SR) aroma/smell (C) and edge or tissue damage (D) for fresh-cut 'Keitt' and 'Palmer' mango cubes stored at 4 °C in modified atmosphere packages (MAP) or JC clam shell containers ( $n = 4 \pm \text{std}$ ).

from each other, with the exception of variety means within a day, and all ripeness  $\times$  day means were statistically different from each another (Fig. 4B).  $\text{CO}_2$  increased, in almost a linear manner, to levels that might alter normal metabolism by day 7. Both packaged SR varieties had significantly higher  $\text{CO}_2$  levels compared with FR cubes (Fig. 4). It has been demonstrated that whole mango fruit ('Keitt') are very tolerant to extremely low  $\text{O}_2$  (0.03–0.5 kPa) and high  $\text{CO}_2$  (72–79 kPa) (Yahia and Hernandez, 1993; Yahia and Vazquez-Moreno, 1993). On the other hand, whole 'Alphonso' mangos stored 21 days in 10 or 15 kPa  $\text{CO}_2$  at 11.1–12.2 °C were not tolerant to high  $\text{CO}_2$  levels (Lakshminarayana and Subramanyam, 1970). Also, tolerance to low  $\text{O}_2$  (i.e. 2 kPa) decreased during ripening in stored whole heat-treated, preclimacteric 'Haden' and 'Tommy Atkins' mangos (Bender et al., 2000b). Mango tolerance to anaerobic conditions appears to vary by variety, ripeness and storage temperature, but the afore-

mentioned referenced comparisons were not for fresh-cuts.

Acceptable appearance, texture and taste were reported after 8–10 days storage at 5 °C in Florida-grown mango slices ('Tommy Atkins', 'Haden' and 'Palmer') that were processed when flesh was yellow (Limbanyen et al., 1998). Fresh-cut mango slices stored at 5 °C in clamshell containers (that attained a modified atmosphere of 2.25 kPa  $\text{CO}_2$  and 19 kPa  $\text{O}_2$ ) did not develop off-flavors (subjectively assessed) compared with control slices, and shelf-life was not improved (Limbanyen et al., 1998). The marketable period for fresh-cut cubes prepared from imported heat-treated 'Tommy Atkins' and 'Kent' fruit (13–27 N) was 3–5 days when held at 10 °C and 5–8 days at 5 °C. The marketable period was extended 1 day (from 3 to 4 days at 10 °C) to 2 days (from 4 to 6 days at 5 °C) when held in 4 kPa  $\text{O}_2$  + 10 kPa  $\text{CO}_2$  or 2 kPa  $\text{O}_2$  + 10 kPa  $\text{CO}_2$  atmospheres (Rattanapanone et al., 2001). Oxygen concentrations did



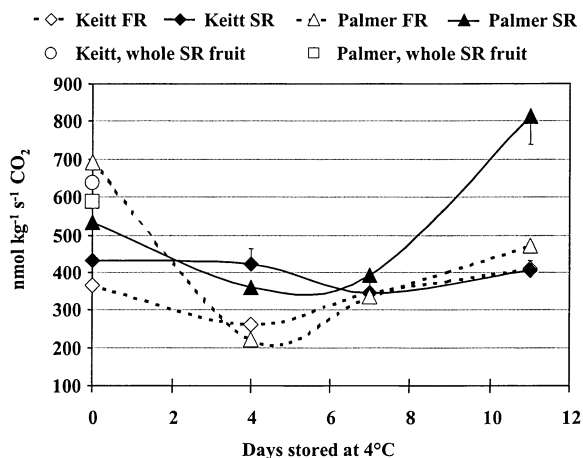


Fig. 3. Respiration rates for fresh-cut ‘Keitt’ and ‘Palmer’ mango cubes stored at 4 °C in JC clam shell containers. Error bars indicate the S.E. associated about the means ( $n = 4$ ), but often did not extend beyond treatment symbols.

not approach anaerobic levels in fresh-cut ‘Kent’ mango slices stored in MAP (González-Aguilar et al., 2000), because fruit were likely quarantine heat-treated, received antibrowning agents, and packaging materials were chosen carefully. Although our SR cubes stored in MAP were obviously “anaerobic” on day 11–14, they had no offensive off-odors or off-flavors (subjective appraisal by the authors). Differences in off-flavor genesis and anaerobic thresholds might be due to genetic background of Indian versus Venezuelan and Florida-grown mango varieties regarding lipid ratios (Gholap, 1975), and the relative concentrations of terpenes and esters (Engel and Tressler, 1983; Idstein and Schreier, 1985; MacLeod and de Troconis, 1982; Malundo et al., 1997). Nonetheless, other factors led to poor overall quality in our MAP treatments prior to 11 days.

### 3.3. Physiological changes

Both FR varieties held in both container types had almost no deviation from their original pH of 2.7 during storage (data not shown). However, both SR varieties held in both containers had significantly ( $P = 0.001$ ) higher initial pH (3.0), which increased to roughly 3.7 by 11 days. There were statistically significant ripeness ( $P = 0.001$ ),

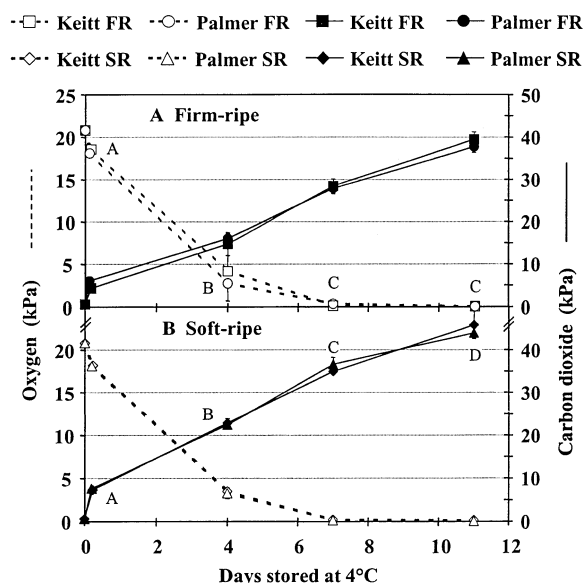


Fig. 4. Percent O<sub>2</sub> (dashed lines) and CO<sub>2</sub> (solid lines) for fresh-cut ‘Keitt’ and ‘Palmer’ firm-ripe (FR) (A) or soft-ripe (SR) (B) mango cubes stored at 4 °C in modified atmosphere packages (MAP) ( $n = 4$ ,  $\pm$ std). Main effect statistical differences for Daily (D) O<sub>2</sub> means are illustrated in panel A, whereas significant variety  $\times$  day ( $V \times D$ ) interaction means for CO<sub>2</sub> are illustrated in panel B (Tukey’s multiple comparison procedure, 0.005 error rate).  $R \times D$  interactions for CO<sub>2</sub> were all significant, but are not illustrated.

variety ( $P = 0.045$ ) and storage time (D,  $P = 0.001$ ) main effects and  $R \times D$  ( $P = 0.001$ ) and  $V \times R \times D$  ( $P = 0.025$ ) interaction effects for pH. The  $V \times R \times D$  interaction means had an increasing pH

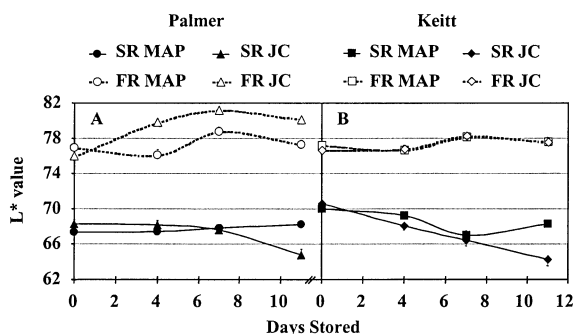


Fig. 5. Hunter L\* (lightness) color in soft-ripe (SR) and firm-ripe (FR) ‘Palmer’ (A) and ‘Keitt’ (B) fresh-cut mango cubes held in modified atmosphere packages (MAP) or JC containers at 4 °C. S.E.s ( $n = \sim 75-80$ ) are posted, but often did not extend beyond treatment symbols.

trend for ripeness; soft ripe with the higher pH's. There was an effervescent-like tongue-feel on day 14 for SR MAP cubes, which must have been due to excessive dissolved CO<sub>2</sub> in the tissue.

Significant L\* color differences ( $P = 0.001$ ) existed between cubes prepared from FR versus SR fruit of both varieties (Table 1, Fig. 5A and B). There was a significant ( $P = 0.025$ ) three-way interaction in lightness (L\*) for container  $\times$  ripeness  $\times$  day. Also, the 'Keitt' SR/JC combination (ripeness  $\times$  container) had a linearly decreasing trend ( $y = 0.574x + 70.474$ ,  $R^2 = 0.999$ ) from 0 to 11 days (Fig. 5). Both SR varieties stored in JC had a significant decrease in L\* values by day 11, which indicates a more dull appearance (Fig. 5A and B). However, much of the JC color decrease occurred after day 7 when most cubes were already unmarketable. Unlike other reports (González-Aguilar et al., 2000; Limbanyen et al., 1998; Rattanapanone et al., 2001), fresh-cuts in our experiments suffered no overall or vein browning during storage. Dulling (L\*) was not problematic in both SR varieties held in MAP. This is similar to reports for fresh-cut 'Tommy Atkins' cubes that were prepared from heat-treated fruit and stored 5 days at 5 °C in low O<sub>2</sub> (0.5–4.0 kPa) (Rattanapanone and Watada, 2000), or CA-stored (4 kPa O<sub>2</sub>, 10 kPa CO<sub>2</sub>) cubes after 5 or 8 days at 10 or 5 °C, respectively (Rattanapanone et al., 2001). Subsequently, the linear color decrease and dulling in SR cubes held in JC containers was likely related to physiological decline; not attributed to surface browning. It would, therefore, be interesting to determine the relative levels of antioxidants like ascorbic acid and carotene in stored fresh-cut mangos.

'Palmer' had significantly higher ( $P = 0.001$ ) °Brix on day 0 for both maturities compared with 'Keitt' (Table 1, Fig. 6). Overall, there was an approximate 3.7 °Brix increase from FR to SR. Only the ripeness main effect means were statistically different throughout the study. °Brix level dropped slightly or held somewhat constant in the FR processed tissue over storage time, but increased markedly during storage from 7 to 11 days, except for 'Palmer' held in JC containers, which markedly declined before the transient increase occurred (Fig. 6A). The general increase

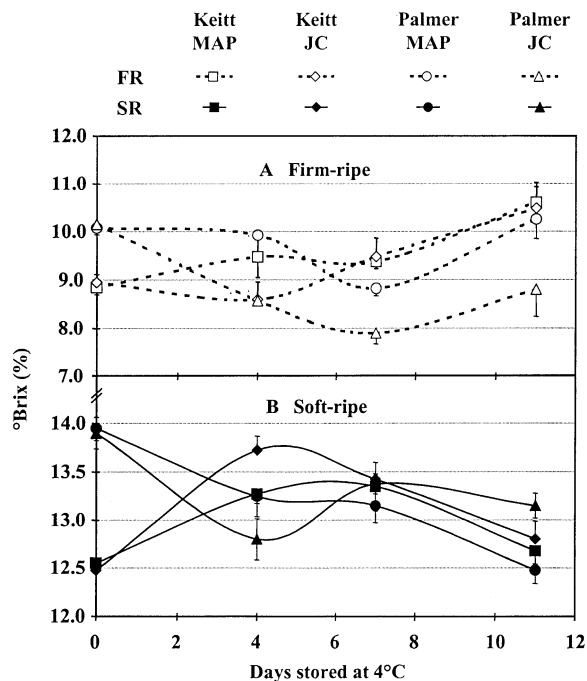


Fig. 6. Change in °Brix (%) for firm-ripe (FR) (A) and soft-ripe (SR) (B) 'Keitt' and 'Palmer' fresh-cut mangos stored in modified atmosphere packages (MAP) or JC containers at 4 °C ( $n = 4 \pm$  S.E.).

in °Brix from 7 to 11 days in FR cubes may indicate that tissue was becoming more ripe (conversion of remaining starch to sugars). Cubes processed with SR fruit displayed °Brix trends that seemed to be variety-dependent. °Brix increased in SR 'Keitt' cubes held in both MAP and JC from 0 to 4 days, then decreased by day 7 or 11, to levels just slightly above their initial day 0 levels (Fig. 6B). On the other hand, °Brix in both JC and MAP SR 'Palmer' cubes decreased dramatically by 4 days in storage, and continued to decrease throughout storage in the MAP treatment. However, °Brix in SR 'Palmer' cubes held in JC increased from 4 to 7 days, then decreased again by day 11, below the initial day 0 levels. °Brix trends likely indicate that SR 'Keitt' cubes were fully ripe by roughly day 4, whereas SR 'Palmer' were likely fully ripe when processed. Soluble solids differed among three initial mango fruit lots, and did not change significantly as a function of temperature, atmosphere or storage time in

fresh-cuts prepared from ripe, heat-treated mangos ('Kent' and 'Tommy Atkins') held at 5 or 10 °C (Rattanapanone et al., 2001). Odd fluctuation in °Brix for fresh-cut 'Haden' and 'Kent' mangos held at 5 °C have also been reported, but these "control" slices were actually dipped into a solution containing CaCl<sub>2</sub>, citric acid, H<sub>2</sub>O<sub>2</sub> and sodium benzoate (Tovar et al., 2001a).

#### 3.4. GC–MS volatile differences and changes through storage

New World and Venezuelan mango varieties generally have lower levels of esters, aldehydes and ketones than Old World varieties. New World mangos (hybrids such as 'Haden', 'Keitt', 'Kent' and 'Tommy Atkins', which originated from Old World stock) predominately contain a mixture of terpene hydrocarbons and oxygenated sesquiterpenoids, often dominated by  $\delta$ -3-carene. As previously reported for mango varieties commonly grown in Florida (Ackerman and Torline, 1984; MacLeod and Snyder, 1985; Malundo et al., 1997; Ollé et al., 1998; Singh et al., 2000), terpenes dominated our volatile profiles. Our method did not recover  $\gamma$ -lactones believed to be important flavor notes in some Indian and Florida varieties (Hunter et al., 1974; Wilson et al., 1990).

Percent O<sub>2</sub> and CO<sub>2</sub> data indicate clearly that the MAP used was inadequate to prevent potential anaerobic respiration, and this was confirmed by significant increases in ethanol, ethyl acetate and ethyl butanoate (Table 3) and acetaldehyde (data not shown) during storage. In all cases, mangos in the JC container had lower "anaerobic" volatile levels. Whole 'Alphonso' mangos stored 21 days in 10 or 15 kPa CO<sub>2</sub> (11.1–12.2 °C), then removed for 7 days to ripen at 27–32 °C had off-flavors and significantly increased alcohol and aldehyde levels (Lakshminarayana and Subramanyam, 1970). Although the MAP containers used in our study could be considered anaerobic after 7 days, no severe off-odors were detected. There were significant ripeness differences for ethyl acetate and ethyl butanoate, and 'Keitt' mangos had lower levels (Table 3). In general, SR fruit stored in JC had higher levels of low molecular weight volatiles such as ethanol, ethyl acetate, ethyl butanoate and

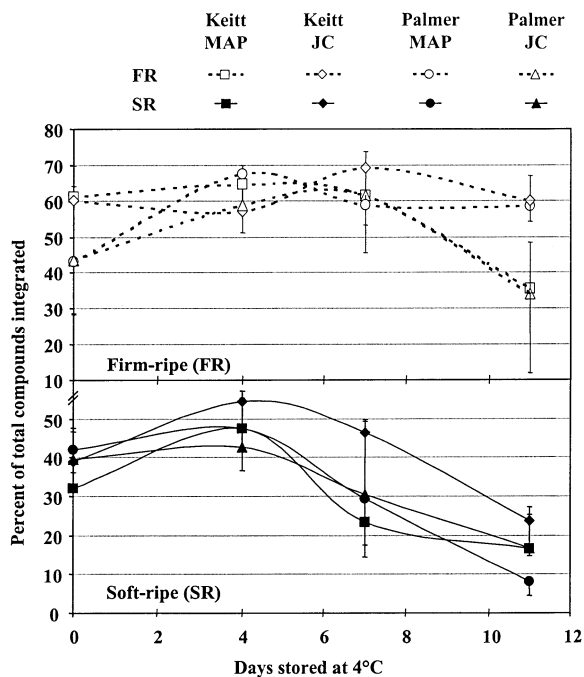


Fig. 7. Relative percent of  $\delta$ -3-carene recovered in firm-ripe (FR) (A) and soft-ripe (SR) (B) 'Keitt' and 'Palmer' fresh-cut mangos stored in modified atmosphere packages (MAP) or JC containers at 4 °C ( $n = 4 \pm \text{std}$ ).

acetaldehyde compared with FR fruit (interaction data not shown).

$\delta$ -3-Carene was the dominant terpene in both varieties in almost all treatments throughout the course of the study, and FR cubes (Fig. 7A) always had significantly higher levels of  $\delta$ -3-carene compared with the respective SR treatment (Fig. 7B, Table 3). The only terpene that displayed significant main effect and interaction means ( $V \times R$ ,  $V \times C$  and  $V \times R \times D$ ) was  $\delta$ -3-carene.  $\delta$ -3-Carene was higher in 'Keitt' and FR fruit, and decreased through storage. On day 0 for FR 'Palmer' and 'Keitt' cubes, 43.3 and 60.6% of the total volatiles was  $\delta$ -3-carene, respectively. Four days later when SR cubes were processed,  $\delta$ -3-carene dropped to 40.8 and 35.5% for 'Palmer' and 'Keitt', respectively. Hence, within 4 days from processing FR versus SR, only "Keitt" fruit lost substantial  $\delta$ -3-carene, which has been associated

with the “green”, “pungent mango leaves” or “lemon” odor attributes (MacLeod and de Troconis, 1982; MacLeod and Pieris, 1984; MacLeod and Snyder, 1985).

Cubes prepared from FR fruit, as compared with SR-prepared cubes, had significantly higher levels of the following terpenes,  $\alpha$ -pinene,  $\beta$ -myrcene,  $\delta$ -3-carene,  $\alpha$ -terpinene, limonene,  $\alpha$ -terpinolene and  $\alpha$ -humulene (a.k.a.  $\alpha$ -caryophyllene) (Table 3). For the main varietal effect, these seven terpenes had  $P$ -values  $< 0.09$  and ‘Keitt’ had higher levels. FR cubes also had higher levels of  $\alpha$ -phellandrene,  $\alpha$ -copaene,  $\beta$ -caryophyllene and two additional terpenes we failed to positively identify (data not shown).  $\beta$ -Caryophyllene and  $\alpha$ -humulene have been ascribed to have attributes such as “woody”; “floral”, “fragrant”; “sickly sweet”, “fresh green” and “wall flowers” in mango (MacLeod and de Troconis, 1982; MacLeod and Pieris, 1984; MacLeod and Snyder, 1985; Ollé et al., 1998). Excessively high terpene levels in immature tissue will produce undesirable flavor notes (Gholap and Bandyopadhyay, 1977; MacLeod and de Troconis, 1982). Hexanal and (*Z*)-3-hexenal were also markedly higher in FR tissue compared with SR for both varieties (data not shown).

Statistical differences in terpene levels between FR and SR cubes during storage were masked by a large experimental error. Nonetheless, there were interesting terpenoid trends during storage. In general, most terpenes displayed a transient increase in both FR and SR cubes, occurring on day 4 or 7, followed by a decline. The percent of total compounds (or quantifying ion abundances) were markedly higher in FR cubes, and the transient trend was more obvious in SR cubes (Fig. 7). After 4 days storage, terpenes generally increased in FR ‘Palmer’ cubes, and MAP generally had higher levels than JC. Whole, non heat-treated MG tree-ripe ‘Tommy Atkins’ mango fruit stored in high  $\text{CO}_2$  (25 kPa) had reduced terpene levels (Bender et al., 2000a). Interestingly, we found that high  $\text{CO}_2$  (MAP storage) was only associated with reduced terpenes in FR ‘Keitt’, and seldom in ‘Palmer’. Fruit processed at FR had similar volatile levels (i.e. highest level for most terpenes) that were comparable to tree-ripe fruit used by

Bender et al. (2000a). In SR cubes, almost all terpenes (i.e.  $\alpha$ -pinene,  $\beta$ -myrcene,  $\delta$ -3-carene, limonene,  $\alpha$ -terpinolene and  $\alpha$ -humulene) followed a similar trend; increasing through 4 days, then dropping off by day 11 to levels just at, or slightly below their initial day 0 level (e.g. Fig. 7). Many volatiles in three of the four SR treatments (but not in ‘Palmer’ JC) displayed a clear transient increase that generally occurred on day 4. In our lab, we have observed similar transient increases in both volatiles and sensory evaluations for other stored fresh-cut fruit products that were prepared with ripe tissue (Beaulieu et al., 2000; Beaulieu and Baldwin, 2002; Beaulieu and Lea, 2003; Bett et al., 2003).

No significant “eating quality” differences were reported in MG ‘Kensington’ mangos that received vapor heat and/or hot water disease control treatments (Jacobi and Giles, 1997), and few differences were noted in control and vapor heat-treated fruit harvested over a 4-week period (Jacobi et al., 1995). These studies, initiated to simulate export market conditions, demonstrated that heat treatments did not seem to affect eating quality. However, one could argue that these eating quality results are suspect since few differences were observed in immature versus MG fruit over 4 weeks, and appreciable quantities of volatiles that appear to be related to superior flavor in fully ripe fruit (Bartley and Schwede, 1987; Gholap, 1975; MacLeod and Snyder, 1985) were likely deficient in MG fruit. Hence, the relatively high level of terpenes and aldehydes we recovered and the extreme variability in FR tissue may provide evidence that initial processing maturity needs to be critically evaluated in order to consistently satisfy consumers; especially if heat-treated imports are processed.

#### 4. Conclusions

To the best of our knowledge, this is the first report documenting volatile and postharvest changes in stored fresh-cut mangos prepared at distinctly different maturities. Many articles have reported volatile data from whole heat-treated (quarantined) and/or MG fruit, but our results

are from cubes prepared from non-heat-treated fruit. Low °Brix, slightly inferior color quality and initial aroma and high terpene levels indicate that fruit processed FR were not ripe enough to deliver an optimum product to consumers, even though storage life was greater than SR cubes. This is corroborated by the fact that stored fresh-cut stone fruits and pears have also been found to lack characteristic flavor when ripeness at cutting was insufficient (Dong et al., 2000; Gorny et al., 1999). On the other hand, the SR cubes were processed when slightly too ripe because they lost subjective qualities (tissue damage, mushiness) faster, even though °Brix and aroma were superior compared with FR cubes.

The terpene volatile data for FR versus SR treatments through storage, when considered along side the °Brix data, indicate that ripening and aroma are very closely related and their attributes often change simultaneously during fresh-cut mango storage. Absolute characterization of initial materials used for processing fresh-cut mango is, therefore, essential to deliver optimum sweetness, flavor and shelf life. The relatively high level of terpenes and aldehydes and the extreme variability in FR tissue indicates that initial processing ripeness stage also needs to be critically evaluated in order to consistently satisfy consumers. However, inherent biological variability, and the impracticality to precisely gauge ripeness in a processing facility will likely remain problematic.

The curious transient increase in volatile compounds warrants more research. Volatile production could undergo a transient upsurge because skin removal creates secondary compound formation (i.e. terpenes and aldehydes), allows rapid off-gassing, and increases available O<sub>2</sub> for enzymatic action. Through storage, as starch declines and less sugar is catabolized, less substrate (Acetyl-CoA) would be available for continued volatile production. Nonetheless, additional research is needed to clearly differentiate ripeness stage-dependent differences in fresh-cut flavor, volatiles and sweetness from various domestic-grown, versus heat-treated and ripened mango varieties.

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