Influence of Harvest Time on Quality of ‘Valencia’ Oranges and Juice

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‘Valencia’ oranges were harvested from Feb. to June 2007, and the effects of harvest time on fruit and juice quality were investigated. After reaching a peak in peel color in March, peel regreening occurred and juice content decreased. Soluble solids content (SSC) remained constant at 10.3% to 11.0% regardless of harvest time. However, juice from later harvested fruit had much lower titratable acidity (TA). Thus, the SSC : TA ratio steadily increased from 10.4 in February to 25.5 in June-harvested fruit. When individual sugars and acids were analyzed, it was found that the ratio increased due to a decrease in citric acid and an increase of sucrose over the season. Pectin content in juice increased with delayed harvest time, possibly due to a softening of albedo and membrane tissues that resulted in small amounts of these materials entering the juice during processing. Ascorbic acid content decreased throughout the harvest season. Phenolic hydroxycinnamic acids (HCAs), an unidentified alkaloid (UA), flavonoids including narirutin (NR), 6,8-di-C-glucosyl apigenin (DCGA) and narirutin-4´-O-glucoside (NRG), as well as limonoids including limonin glucoside (LG), nomilinic acid glucoside (NAG), and limonin (L) and nomilin (N) aglycones were measured over the season. Total levels of the HCAs decreased continually until May then increased in June, and the alkaloid, UA, continually increased during the entire harvest season. Contents of flavonoids decreased or remained constant. Limonoids, including L and N, the major bitterness contributors, decreased over the season except LG and NG, which peaked in May. Volatile production for most compounds increased with delayed harvest time at least until May, including acetaldehyde, octanal, hexanal, decanal, ethanol, hexanol, E-2-hexenol, linalool, octanol, α-pinene, mycene, limonene, ethyl butanoate, ethyl hexanoate and methyl butanoate. Some compounds, such as methanol, valencene and ethyl acetate decreased with delayed harvest. Z-3-Hexenol and α-terpineol showed similar patterns, decreasing in April and May and increasing thereafter. The results indicate that fruit harvested in earlier in the season had better quality in terms of higher juice content, better SSC/TA ratio (April to May, 15.1–18.6 ratio), higher levels of ascorbic acid, and lower levels of bitter components. However, fruit harvested later in the season likely had more aroma and lower levels of bitter components.

‘Valencia’ is the predominant orange variety grown in Florida and is mainly used for juice. This variety has a deep orange color and rich flavor that is superior to other varieties. The harvest season for ‘Valencia’ oranges destined for processed juice can extend for up to 4 months (March to June) after they first reach acceptable maturity (Soule et al., 1967). Florida maturity indices for oranges harvested between 16 Nov. to 31 July are: soluble solids content (SSC, ~ Brix) > 8.5%, titratable acidity (TA) > 0.4%, SSC:TA ratio >10.25, and juice content > ~45 mL/100 g (4.5 gal per 1.6 bushel box) (Ritenour, 2004). There is a gradual decrease in TA by decomposition of citric acid, as well as a slight increase in SSC and a consistent increase of SSC:TA ratio (Chen, 1990; Hutton and Landsberg, 2000).

Orange fruit and juice are immensely popular worldwide for their flavor and nutrition. The essence of orange flavor is a complex mixture of volatile compounds of which some 200 have been identified (Johnson et al., 1996). The most important volatiles are esters, aldehydes and terpenes, followed by alcohols, ketones, and hydrocarbons (Nisperos-Carriedo and Shaw, 1990; Plotto et al., 2004, 2008; Shaw, 1991). However, information is lacking concerning development of flavor volatiles in citrus fruit during ripening (Baldwin, 1993).

The nutritional value of orange can be linked in part to the secondary metabolite contents, including numerous flavonoids (Horowitz and Gentili, 1977; Nogata et al., 2006), limonoids (Maier et al., 1980; Manners et al., 2003), and hydroxycinnamates (Kroon and Williamson, 1999; Risch and Hermann, 1988). Secondary metabolites in orange may also contribute to fruit and juice quality in many ways, influencing the appearance, the taste as well as the nutritional value (Baldwin, 1993). It has been noticed previously that bitterness and limonin, a major bitter compound in oranges, decreased during the harvest season (Maier...
et al., 1980). However, very little attention has been given to the seasonal changes of other secondary metabolite compositions. The goal of this study was to evaluate appearance, flavor, and nutritional qualities of ‘Valencia’ fruit and juice associated with harvest time over the 4-month commercial season.

**Materials and Methods**

**Fruit Sampling.** Fruit were harvested from five trees grown in a commercial orchard located in southern Florida on 13 Feb., 19 Mar., 13 Apr., 15 May, and 29 June 2007. At each harvest time, 30–40 fruit were picked from each replicate tree. After measuring peel color, the fruit were sanitized with 200 ppm NaOCl for 30 s, and gently hand juiced using a Sunkist J1 Commercial Citrus Orange Juicer (Sherman Oaks, CA). Halved fruit were pressed onto the automatic self-reversing reamer, and seeds and segment membranes were screened by a strainer. The juice was lightly pasteurized (71 °C for 15 s in a water bath) and frozen at –20 °C until analysis.

**Color and Juice Ratio Analysis.** For peel color, fruit were evaluated using a Minolta Chromometer (Model CR-300, Minolta, Tokyo, Japan) measuring a* and b* values for red/green and yellow/blue color, respectively, and expressed as a*:b* ratio. Juice color was measured with a Macbeth Color-Eye 3100 spectrophotometer (Kollmorgen Instruments Corp., Newburgh, NY) and expressed as color number.

**Sugar and Acid Analysis.** Titratable acidity (TA) was determined by titrating to pH 8.1 with 0.1 N NaOH using an autotitrator (Metler Toledo DL50, Daigger & Company, Vernon Hills, IL) and soluble solids content using a refractometer (Ataqa RX-5000 cx, Tokyo, Japan).

Individual sugar and acid analyses were performed using an HPLC. For sugar analysis, juice samples were centrifuged at 20,000 × g for 15 min; aliquots of the clarified supernatants were diluted 20x with water. Dilute juice was passed through a C-18 Sep-Pak column (Waters/Millipore, Milford, MA) and filtered through a 0.2-µm nylon filter. Aliquots (1 mL) of the extracts were transferred to 1.5 mL autosampler vials for analysis. Sugars were analyzed by a Shimadzu (Tokyo, Japan) LC-20 AD Promi

**SUGAR AND ACID ANALYSIS.** Individual sugar and acid analyses were performed using an HPLC. For sugar analysis, juice samples were centrifuged at 20,000 × g for 15 min; aliquots of the clarified supernatants were diluted 20x with water. Dilute juice was passed through a C-18 Sep-Pak column (Waters/Millipore, Milford, MA) and filtered through a 0.2-µm nylon filter. Aliquots (1 mL) of the extracts were transferred to 1.5 mL autosampler vials for analysis. Sugars were analyzed by a Shimadzu (Tokyo, Japan) LC-20 AD Prominence Solvent Delivery System (DGU-20AS On-line Degasser, SIL-20A Autosampler, CMB-20A System Controller) equipped with an ELSD-LTI2 Detector (Sedex Model 85 Low Temperature Evaporative Light Scattering Detector). The column used was the 700 CH Carbohydrate (300 mm × 6.5 mm) (Alltech, Nicholasville, KY) operated at 90 °C in a column heater (Timberline Instruments Model 105). The mobile phase was water at a flow rate of 0.5 mL·min⁻¹. Samples of 10 µL were analyzed. Quantification of sugars was based on the external standard method (EZStart Chromatography software, Agilent, Santa Clara, CA). All results are expressed as grams of sugar per 100 mL juice.

For analysis of individual acids, approximately 40 g of juice was extracted using 70 mL 80% ethanol solution. The mixture was boiled for 15 min, cooled, and filtered (Whatman #4 filter paper). The filtered solution was brought to 100 mL with 80% ethanol. Ten milliliters of the filtered solution were then filtered through a C-18 Sep-Pak (Waters/Millipore) followed by a 0.45-µm Millipore filter (Baldwin et al., 1991). Organic acids, including ascorbic acid, were analyzed using an Altech OA 1000 Preval organic acid column (Altech Corp., Flemington, NJ) with a flow rate of 0.2 mL·min⁻¹ at 35 °C and a mobile phase of 0.01 N H₂SO₄. The injection volume was 20 µL using a Perkin Elmer Series 200 autosampler, a Spectra System P4000 pump and a Spectra System UV 6000 LP detector (Shimadzu) was used for the analysis.

For galacturonic acid, each juice sample was adjusted to pH 2.4 with nitric acid. A 7.0-mL aliquot was heated for 5 min at 110 °C in a glass extractor using a microwave (Discover model 908005, CEM Corp., Mathews, NC) and immediately cooled to room temperature then centrifuged for 30 min at 1000 × g (Luzio, 2008). Each supernatant was mixed with 14 mL of cold anhydrous isopropyl alcohol, refrigerated for 60 min at 4 °C and centrifuged for 1 h at 3000 × g. Supernatant was discarded and the pellet washed once with anhydrous isopropyl alcohol (IPA) and then twice with 70% IPA and centrifuged at 3000 × g for 1 h between each wash while discarding all supernatants. Pellets were dried for 16 h at 50 °C in the centrifuge tube under vacuum. A glass marble and 4 mL of deionized water was added to the dry pellet and then shaken for 24 h. To an 800-µL aliquot of the rehydrated sample, 200 µL of 0.5 mol sodium acetate buffer (pH 5.0) and 2 µl of pectinase (Pectinex Ultra SP-L, P-2611, Sigma-Aldrich, St. Louis, MO) was added (Grohmann and Baldwin, 1992). Samples were then incubated at 37 °C for 24 h and then centrifuged for 5 min at 14,000 × g. Determination of galacturonic acid was performed on the supernatants using an anion exchange chromatography (CarboPac PA1 column, Dionex Corp., Sunnyvale, CA), using 0.0 to 0.5 mol ammonium formate (Fluka Anal. #09735, Sigma-Aldrich, St. Louis, MO) gradient elution with a binary pump (model series 200, Perkin Elmer, Waltham, MA) set at a flow rate of 0.6 mL·min⁻¹ (Cameron et al., 2003). Evaporative light scattering was used for detection (Sedex model 85, Sedere Sas, Alfortville Cedex, France) set at an evaporator temperature of 99 °C, photomultiplier gain of 9 and nebulizer air pressure of 4.5 atm. Data were collected and analyzed with EZChrom Elite software (version 3.1.6, Agilent).

**SECONDARY METABOLITE ANALYSIS.** For sample preparation, juice extracts were prepared to minimize free sugar content, yet be inclusive of the soluble and particulate bound polar and non-polar secondary metabolites. Shaken and thawed orange juice (2 mL) was added to 13 mL methanol, shaken, then passed through a 0.45 µm PTFE filter. The filter was washed with an additional 0.5 mL methanol, and the total volume was adjusted to 15 mL. To 12.0 mL methanolic juice extract, 1 mL butanol was added, and the sample was taken to dryness using a Savant centrifugal evaporator. Methanol (2 mL) was added, and each sample was vortexed for 2 min. Samples were centrifuged for 5 min, then the recovered clear supernatants were quantitatively removed and adjusted to 4.0 mL prior to analysis by HPLC-MS.

Land N were additionally extracted from centrifuged (10,000 × g for 15 min) juice samples (150 mL) 3 times with equal volumes of methylene chloride. The combined methylene chloride extracts were dried under vacuum and the resulting residues dissolved in 12 mL aceton. The acetone solutions were clarified by passage through a 0.45-µm PTFE filter, then evaporated with a Savant centrifugal evaporator. The residues were again dissolved in acetone (1.0 mL) acetone containing 4.35 µg hesperitin internal standard prior to analysis by HPLC-MS.

A Waters 2695 Alliance HPLC (Waters, Medford, MA) connected in parallel with a Waters 996 (Photo Diode Array) PDA detector and a Waters/Micromass ZQ single quadrupole mass spectrometer equipped with an electrospray ionization source was used for the analysis. Compound separations were achieved with a Waters XBridge C8 column (4.6 × 150 mm). Elution conditions included a three solvent gradient composed initially of water/acetonomide/0.5% formic acid (85/10/5, v/v/v), and increased with linear gradients to 75/20/5 (v/v/v) over 10 min, then
to 70/25/5 (v/v/v) by 15 min, then to 55/40/5 and 25/70/5 (v/v/v) by 23 min and 40 min, respectively, at a flow rate of 0.75 mL·min⁻¹.

Data handling was done with MassLynx software ver. 3.5 (Micromass, Division of Waters Corp., Beverly, MA). Post column split to the PDA and mass ZQ detector was 10:1. MS parameters were as follows: ionization mode, ESI⁺; capillary voltage 3.0 kV; extractor voltage 5 V; source temperature 100 °C; desolvation temperature 225 °C; desolvation N2 flow 465 L·h⁻¹; cone N2 flow 70 L·h⁻¹; scan range m/z 150–1600; scan rate 1 scan per second; cone voltages 20 and 40 eV.

Quantifications of the secondary metabolites were made using either ZQ calculated mass extracted Total Ion Chromatograms (TIC) obtained in scanning mode, or by single ion response (SIM) mode. To normalize the mass spectrometer instrument response during sequential runs, an internal standard, hesperetin, was additionally measured at 303 m/z. Endogenous hesperetin accounted for less than 1% of the total level after addition of hesperetin (4.35 µg) as an internal standard.

Quantitative limonoid analyses were conducted using modified methods of Manners et al. (2003). Limonoid glucosides were monitored with positive electrospray ionization (+20 V) measured with the main fragment ions corresponding to the protonated aglycone mass ions [471 m/z for limonin (L), and 515 m/z for both nornolin (N) and nornilinic acid (NA)]. The TICs for L and nomilin N were monitored at +40 V. Identifications of the limonoid glucosides and aglycones were made based on the detection of the fragment ions co-eluting with authentic standards. Similar techniques were used to detect and measure the levels of selected phenolic secondary metabolites in the orange fruit, including: feruloyl putrescine (FP, 265 m/z), narirutin-4´-O-glucoside (NRG) and narirutin (NR, 273 m/z), and 6,8-di-C-glucosyl apigenin (DCGA, 393 m/z).

**Volatile analysis.** Two milliliters of the headspace of 10-mL crimped-capped vials with 3 mL of thawed juice was injected onto an Agilent 6890 GC using a Gerstel multipurpose autosampler equipped with Stabilwax and HP-5 low bleed columns. The flow rate was split equally to the two columns at 17 mL·min⁻¹ at 40 °C with an increase in temperature at 6 °C per minute up to 180 °C, where the temperature was held constant for an additional 5.8 min. The GC peaks for the aroma volatile compounds were quantified using standard curves as determined by enrichment of deodorized orange juice by known concentrations of authentic volatile compound standards (Nisperos-Carriedo and Shaw, 1990).

**Statistical analysis.** SAS Version 9.1 (SAS Institute, Cary, NC) was used to analyze the data, using analysis of variance (PROC ANOVA). Mean separation was determined by Duncan’s multiple range test at the 5% level.

**Results and Discussion**

**Peel color, juice color, and juice ratio.** The a* / b* ratio (a* is a measure of redness/greenness and b* is a measure of yellowness) serves as an indicator of quantitative development of orange color (Ayres and Tomes, 1966). A greater a* / b* ratio is a sign of deeper orange color, and a negative value shows more green than orange. The peel a* : b* ratio increased from February to March, the beginning of commercial harvest for ‘Valencia’ oranges, then decreased over the harvest season, indicating an ongoing regreening of fruit peel after reaching harvest maturity (Fig. 1A). This phenomenon is quite common in Florida due to the humid hot weather (Ritenour, 2004). According to Stearns and Young (1942), color break results from temperatures below 13 °C in Florida. During regreening, chromoplasts were converted to chloroplasts (Mayfield and Huff, 1986). This involves de novo synthesis of chlorophyll and protein components of the photosynthetic apparatus (Mayfield and Huff, 1986) as well as realignment of thylakoid structures (Thomson et al., 1967).

Juice color number was 37.3 in February, rapidly increased to 39.4 in March as commercial harvest began (Fig. 1B). The high values were maintained in April, however, decreased thereafter. Juice color is a primary quality attribute for orange juice. A USDA score of 36–40 is considered to be grade A, and 32–35 constitutes grade B for most citrus products (Kimball et al., 2004; Stewart, 1980). A higher color number reflects deeper-colored juices. Carotenoid pigments are responsible for orange juice color. Tropical climates generally grow fruit that produce lighter color juices (Kimball et al., 2004; Lee and Coates, 2003).

Juice content was 57 mL·100 g⁻¹ fruit in February, declined over the season except for a slight increase in May (Fig. 1C). In June, the content was below 44 mL·100 g⁻¹, lower than the Florida orange juice standard of 45 mL·100 g⁻¹ (Ritenour, 2004). A possible reason is that after the fruit reach harvest maturity and juice sacs stop growing, the peel may grow again along with peel regreening. This is in agreement with Harding et al. (1940). Juice content is fairly negatively correlated with peel thickness (Bitters, 1960). Nevertheless, Bartholomew et al. (1950) observed that juice content of ‘Valencia’ kept increasing over the season in California.

**Sugars and acids.** SSC of juice was about 11 throughout the entire harvest season with a slight decrease in April, but increasing thereafter (Fig. 1D). However, TA content decreased consistently from 0.97% in February to 0.43% in June (Fig. 1E). Consequently, SSC/TA ratio increased from 10.4 in February to 25.5 in June (Fig. 1F). All juices passed Florida juice standard (Ritenour, 2004), except fruit harvested in June, which had too high a ratio of SSC/TA. A high quality juice has a ratio between 12.5 and 19.5 (Matthews, 1994) and eventually overripe and unpleasantly sweet, low acid fruit reach a SSC/TA ratio of 20 or higher (Baldwin, 1993). Of the soluble solids, major components are sucrose, fructose and glucose with a ratio of 2:1:1, respectively (Kimball et al., 2004). After reaching harvest maturity, fructose and glucose remained constant, however, sucrose increased steadily (Fig. 1G–I). In contrast, glucose increased but other sugars were constant from March to May in ‘Valencia’ peel (Wilkins et al., 2005). Consequently, total sugar content and sweetness, expressed as sucrose equivalents, also increased after March, which is the beginning of the commercial harvest season (data not shown). Ratio of total sugars to SSC increased from 81% in March to 89% in April, and remained at high levels thereafter (Fig. 1J). Citric acid, the principal organic acid, decreased throughout the harvest season; however, malic acid (9% to 15% of total organic acids) slightly increased (data not shown). Succinate and isocitrate are also components of orange acids (Baldwin, 1993), however, only trace levels were detected in these samples (data not shown). The decrease in TA in fruit during ripening may be partly due to dilution with increased fruit size (Kimball, 1984). In mature orange juice sacs, both aconitase and citrate lyase activities were absent (Escheverria and Valich, 1988). The regulation of citrate formation may be by decreasing synthesis of oxaloacetate, the precursor of citrate, during maturation (Brummer, 1989).

Total ascorbic acid content decreased consistently during harvest season (Fig. 1K), which is in agreement with Harding et al. (1940) and Rygg and Getty (1955). Galacturonic acid is the main component of pectin. Galacturonic
Acid content in juice increased from 0.037 mg·g⁻¹ in March to 0.31 mg·g⁻¹ in June (Fig. 1L), which is over an 8-fold increase. This is in contrast to Sinclair and Jolliffe (1958, 1961) and Rouse et al. (1962) who observed that in maturing oranges, total pectin and water-soluble pectic substances decreased in the peel and pulp, in both California and Florida ‘Valencia’ fruit. A possible reason of the increase of juice pectin is that when fruit were harvested later, a softening of albedo and membrane tissues may have occurred that resulted in small amounts of these materials entering the juice during processing. The late harvested fruit can be problematic because of the high pectin content in juice.

Secondary metabolites. Several classes of secondary metabolites were measured in the ‘Valencia’ orange juice between March and June 2007. These classes of compounds consisted of: hydroxycinnamic acids (HCAs) including two unidentified compounds with HPLC elution times of 6.3 and 7.2 min, feruloyl putrescine (FP), an unidentified alkaloid (UA), a number of flavonoids including narirutin (NR), 6,8-di-C-glucosyl apigenin (DCGA) and narirutin-4′-O-glucoside (NRG), as well as limonoids, including limonin glucoside (LG), nomilinic acid glucoside (NAG), limonin (L) and nomilin (N) aglycones. The HCAs, along with FP, decreased from March to May and then increased thereafter (Fig. 2A–C). UA remained constant from March to April, and then continually increased until June (Fig. 2D). Of four flavonoid components analyzed in this experiment, the most abundant component was hesperidin, (data not shown), followed by NR (48–50 µg·mL⁻¹), DCGA (29–43 µg·mL⁻¹), and NRG (10–22 µg·mL⁻¹) (Fig. 2E–G). DCGA and NRG did not have significant changes throughout the entire harvest season, although they showed a slight decreasing trend.
NR also remained level in March and April, but sharply decreased from April to May, then remained constant thereafter (Fig. 2E).

All five limonoids tended to decrease throughout the harvest season (Fig. 2H–L). Of those components, L and N are major contributors to bitterness in citrus (Maier et al., 1980). A comprehensive study of L taste thresholds in orange juice was reported by Guadagni et al. (1973; 1976). The most sensitive individual had a limonin threshold of 0.5 µg·mL⁻¹ while that of the least sensitive was 32 with an average group threshold 6 µg·mL⁻¹ (Guadagni et al., 1976). The range of L throughout the maturation was 0.5 – 0.9 µg·mL⁻¹, at the low end of perceptible levels. Robertson and Nisperos (1983) reported that L levels decreased in citrus fruits with advancing maturity. Kimball (1984) pointed out that dilution and degradation during ripening causes decreases in L levels. Both LG and NG had a significant peak in May (Fig. 2H and I).

Aldehydes have been considered important to orange flavor (Baldwin, 1993; Selli et al., 2004; Shaw, 1991). Acetaldehyde production increased from March to April and then remained constant over the rest of the season (Fig. 3A). Acetaldehyde was found to be an important contributor in orange juice “freshness” (Byrne and Sherman, 1984; Shaw, 1991). Octanal is another important aldehyde in orange juice with a flavor threshold value of 0.233 µg·mL⁻¹ in orange juice matrix (Plotto et al., 2004). It was low in March and April, however, increased to 0.53 µg·mL⁻¹ in May (Fig. 3B), more than two times its flavor threshold values. Hexanal increased from April to June (Fig. 3C), but might not be a key volatile for orange flavor (Buettner and Schieberle, 2001). Decanal, an important flavor compound (Ahmed et al., 1978) with abundant values increased until May and decrease thereafter (Fig. 3D).

Methanol production decreased with delayed harvest (Fig. 3E). A likely source of methanol in fruit is from pectin demethylation in the cell walls (Fall and Benson, 1996; Gout et al., 2000; O’Neill et al., 1990). The degrees of methylation of acid-extracted pectins during maturation in March to June are 9.61% to 11.16%, fairly stable in peel, membrane and juice sacs (Rouse et al., 1962). Decrease of methanol may be associated with decreased pectin content which fits with the data that show total pectin decreasing with maturation (Rouse et al., 1962; Sinclair and Jolliffe, 1958; Sinclair and Jolliffe, 1961). However, this is not in agreement with the galacturonic acid results measured in this research. Maybe there is another pathway that caused the increase of methanol.

Ethanol content in juice increased consistently (Fig. 3F). A possible mechanism for the accumulation of ethanol is that, with delayed harvest, gas permeability of fruit tissues decreased,
possibly causing partial anaerobic conditions inside the fruit. Senescence of fruit may also cause ethanol fermentation in apples (Ueda et al., 1993). Although there were relatively high levels of ethanol, there is small impact on juice flavor due to the high threshold value of ethanol (Plotto et al., 2008; Shaw, 1991).

Hexanol increased until May and then decreased (Fig. 3G). Z-3-hexenol and E-2-hexenol contribute important fruity-green top notes to fruit flavor (Shaw, 1991). Z-3-hexenol had high values in March and June but dipped in April and May (Fig. 3H). E-2-hexenol had low values in March and April, however sharply increased in May and remained at high levels thereafter (Fig. 3I). Linalool, also important for orange flavor, increased from March to May and remained constant thereafter (Fig. 3J). Octanol showed a sharp increase from April to May (Fig. 3K). α-Terpineol, generally considered to make a negative contribution to orange flavor (Shaw, 1991), decreased from March to May, however, increased to the highest level in June (Fig. 3L).

Limonene and α-pinene are two major volatile constituents in orange juice (Ahmed et al., 1978; Shaw, 1991). Both compounds increased slightly from March to April, sharply from April to May, then remained constant (Fig. 3M and 3N). Their levels in orange juice depend on the peel oil content of the juice, and are

Fig. 3. Effect of harvest time (Mar.–June 2007) on volatile abundances of 'Valencia' orange juice. Mean values labeled with the same letter are not different at the 5% level.
easily influenced by processing methods (Ahmed et al., 1978; Shaw, 1991).

Myrcene is another abundant terpene in orange juice, which makes a negative contribution (Ahmed et al., 1978; Shaw, 1991). It showed a similar pattern to α-pinene and limonene during the harvest season: sharply increasing from April to May, but remaining constant before and after that period (Fig. 3Q). Valencene is a sesquiterpene hydrocarbon which has little effect on orange juice flavor (Ahmed et al., 1978; Shaw, 1991). Valencene content continually decreased from March to May and then remained constant (Fig. 3P).

Of the esters identified in orange juice, ethyl butanoate is the most important contributor to orange flavor with a pleasant, strong, fruity aroma (Ahmed et al., 1978; Shaw, 1991). It increased in the first month and then remained constant during rest of the season (Fig. 3Q). Ethyl acetate decreased during the season (Fig. 3R). Ethyl hexanoate and methyl butanoate increased from March to May then decreased in June (Fig. 3S and 3T).

As described above, volatile production for most compounds increased with delayed harvest time at least until May (some dropped off in June), including acetaldehyde, octanal, hexanal, decanal, ethanol, hexanol, E-2-hexenol, linalool, octanol, α-pinene, myrcene, limonene, ethyl butanoate, ethyl hexanoate and methyl butanoate. Some compounds, such as methanol, valencene and ethyl acetate decreased with delayed harvest. Z3-hexenol and α-terpineol showed similar patterns, decreasing in April and May and increasing thereafter.

Conclusion

‘Valencia’ oranges are harvested commercially from March to June, although April and May harvests are preferred for the optimum SSC, TA, ratio, and reduced bitterness. Later harvested ‘Valencia’ fruit have better volatile profiles, while concentrations of a number of the key secondary metabolites appear to occur at higher levels in earlier season fruit.

Literature Cited


