

A Sensory and Chemical Analysis of Fresh Strawberries Over Harvest Dates and Seasons Reveals Factors That Affect Eating Quality

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ABSTRACT. The aim of this study was to understand the flavor components of eating quality of several strawberry (*Fragaria ×ananassa* Duch.) genotypes grown in Florida over two harvest seasons. Five selections and one cultivar of the University of Florida Breeding program as well as two new cultivars from Australia ('Rubygem' and 'Sugarbaby') harvested on different dates from the same grower were evaluated by sensory evaluation. 'Festival', the main strawberry cultivar grown in Florida, had low ratings for flavor and sweetness in January and March. Selection FL 00-51 and 'Rubygem' had relatively high and consistent ratings for flavor and sweetness compared with the other selections. Genotypes with low flavor ratings were always judged as "not sweet enough" by the panelists, thus linking flavor to sweetness preference. Instrumental analysis confirmed that typically these selections had low soluble solids content (SSC) and/or high titratable acidity (TA), thus explaining their lack of sweetness. Volatile compounds that varied only quantitatively did not seem to influence the flavor rating except for 'Sugarbaby'. This cultivar contained between seven and 40 times less total ester content than the other selections and was disliked by panelists despite its high sugar content and perceived sweetness. It was perceived as having an artificial peach- or blueberry-like flavor. A principal component analysis was performed with chemical parameters (SSC, TA, and volatile content) and selections over the two harvest seasons. Chemical composition was mainly influenced by harvest date, except for FL 00-51. This selection maintained high volatile content and SSC throughout the seasons, explaining consistently high flavor ratings.

The sensory quality of strawberry is the result of a complex balance among sweetness, aroma, texture, and appearance. Some authors have investigated the relationship between sensory quality attributes and instrumental analysis (Hoberg and Ulrich, 2000; Pelayo et al., 2003; Pelayo-Zaldívar et al., 2005; Schulbach et al., 2004; Shamaila et al., 1992; Ulrich et al., 1997; Wozniak et al., 1997). Sugar and volatile contents were found to be important biochemical components that influence consumer acceptance. Wozniak et al. (1997) showed a correlation between the overall sensory quality of some California cultivars and the sugars/acid ratio in maturing fruit. Pelayo-Zaldívar et al. (2005) reported that consumer preference for some California strawberries was related to higher sugar and volatile contents. The influence of volatile compounds on the flavor quality of the strawberry was widely studied, and among the hundreds of volatiles identified in fresh strawberry, only a small portion contribute to aroma (Dirinck et al., 1981; Larsen and Poll, 1992; Pérez et al., 1992; Ulrich et al., 1997). Recently, Ulrich et al. (2007) showed that the intense aroma of wild

species was associated with their high ester and terpene contents. Esters are known to be important contributors to typical strawberry aroma (Gomes da Silva and Chaves das Neves, 1999; Larsen and Poll, 1992; Pérez et al., 1992; Schieberle and Hofmann, 1997). Among them, methyl and ethyl butanoates, methyl and ethyl hexanoates, and ethyl 2-methyl butanoate are often mentioned as active aroma compounds in strawberry. Furanones (furanol and mesifurane) are also contributors to aroma providing sweet caramel-like notes (Larsen and Poll, 1992; Pérez et al., 1996; Sanz et al., 1994). Additionally, aldehydes and alcohols such as n-hexanal, (Z)-3-hexenal, and (E)-2-hexenal are responsible for green and pungent notes (Schieberle and Hofmann, 1997; Schulbach et al., 2004).

Strawberry is second only to citrus (*Citrus* L.) as a fruit crop of importance to Florida with Florida being the principal supplier of fresh strawberries to eastern and midwestern United States during December, January, and February. Extending the commercial season into the month of March would close the gap with strawberries produced in more temperate areas. 'Festival', the main cultivar grown by the large commercial strawberry farms in Florida, produces firm, attractive fruit, which are flavorful if harvested fully mature. However, the size and flavor of this cultivar's fruit are affected by the harvest date and tend to be less than optimum in March. The goals of this study were to reveal 1) the factors that affect the eating quality of promising selections in the University of Florida breeding

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program; and 2) the impact of harvest date on fruit chemical and sensory characteristics. This information may help identify selections that are complementary to 'Festival'.

Materials and Methods

PLANT MATERIAL. Five strawberry selections from the University of Florida (FL 95-269, FL 99-164, FL 99-117, FL 00-51, FL 01-116) and one commercial cultivar (Festival) were tested in 2006. In 2007, five genotypes were retested ('Festival', FL 99-164, FL 99-117, FL 00-51, FL 01-116), and two named cultivars were added, 'Rubygem' (Herrington et al., 2007) and 'Sugarbaby' (U.S. Plant Patent no. 16766) (only February and March). Fruit were harvested at commercial maturity (three-fourths to full red) on 1 Feb. and 8 Mar. 2006 and on 3 Jan., 12 Feb., and 14 Mar. 2007. They were harvested from the same fields both years on the day before the panel, stored at 5 °C overnight, and transferred to room temperature 2 h before the panel began. Fruit were washed, drained, and patted dry with paper towels immediately before serving. Enough fruit were harvested to provide for sensory evaluation and sampling for analytical measurements.

SENSORY EVALUATION. The sensory study took place at the University of Florida's Gulf Coast Research and Education Center in Wimauma. Participants were employees from and visitors to the center willing to consume strawberries. Six or seven tasting stations, coded A through G corresponding to the selection codes, were arranged around a large central laboratory table. In 2006, 50 and 51 panelists participated in the February and March panels, respectively, with 62% to 63% female panelists. In 2007, 60 to 66 panelists (36% to 52% female panelists) participated in the taste panels. Panelist ages ranged from younger than 26 to older than 65 years old with the majority of panelists between 36 and 55 years old. Approximately half of all panelists were repeat tasters.

Strawberries were presented in bulk on a 23-cm diameter plate at each station. Unsalted crackers and spring water were provided for cleansing the palate between samples. Panelists were asked to taste the berries following the codes written on their ballot sheets and answer the questions on the ballots. Presentation was randomized across panelists and serving order was balanced so that each sample was tested in each position (first, second, third, fourth, fifth, sixth). In Feb. 2006, panelists were asked to rate samples for appearance, flavor, sweetness, tartness, and texture on a 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely). Because the 9-point hedonic scale did not provide information on the acceptable level of sweetness and tartness, the sweetness and tartness scales were changed to a 5-point just-right scale (1 = not sweet/sour enough; 3 = just right; 5 = too sweet/sour) for the rest of the study. A line for comments was provided after each question.

FRUIT PREPARATION. For each selection, ≈ 10 fruit cut in halves (80 g) were homogenized for 20 s in a blender. A volume of 2.5 mL of this puree was introduced into a 20-mL vial with 3-hexanone as an internal standard ($1 \mu\text{L}\cdot\text{L}^{-1}$) (Sigma-Aldrich, St. Louis, MO). Saturated aqueous CaCl_2 (2.5 mL) was added after 1 min to reduce enzymatic activity (Buttery, 1993). The vials were sealed with magnetic crimp caps (Gerstel, Baltimore, MD), agitated using a Genie 2 vortexer (Scientific Industries, Bohemia, NY) for several seconds, and stored at -80°C until analysis. The rest of the homogenate (≈ 50 mL) was poured into

centrifuge tubes for analysis of titratable acidity and soluble solids content and all vials and tubes were frozen at -20°C until analysis. This procedure was replicated four times for each selection.

TITRATABLE ACIDITY AND SOLUBLE SOLIDS CONTENT. The supernatant of thawed homogenates centrifuged at $12100 g_n$ for 10 min was analyzed for titratable acidity (TA), pH, and soluble solids content (SSC). For TA, 6 g of the supernatant was diluted with 50 mL DI-water and titrated with 0.1 N NaOH to pH 8.1 end point using a Metrohm 808 Titrando and 730 sample changer (Metrohm USA, Westbury, NY). SSC of the supernatant was determined with a digital ATAGO PR-101 refractometer with a 0% to 45% Brix range (Atago, Tokyo, Japan).

EXTRACTION OF VOLATILES COMPOUNDS. Frozen homogenate/ CaCl_2 solution mixtures were thawed at room temperature and volatiles were extracted using a 2-cm SPME fiber (50/30 μm DVB/Carboxen/PDMS; Supelco, Bellefonte, PA), which was found to give the most representative extract by smell among three types of fiber tested (Jouquand et al., 2008). After a sample equilibration time of 10 min at 40°C , the fiber was exposed to the headspace for 30 min at 40°C . The fiber was then introduced into the injector of the gas chromatograph-mass spectrometer for 5 min at 250°C for desorption of volatiles.

IDENTIFICATION AND QUANTITATION OF VOLATILE COMPOUNDS USING GAS CHROMATOGRAPHY-MASS SPECTROMETRY. Identification of volatile compounds was carried out using an Agilent 6890 GC coupled with a 5973N MS detector (Agilent Technologies, Santa Clara, CA). Inlet, ionizing sources, and transfer line temperatures were kept at 250, 230, and 280°C , respectively. Mass units were monitored from 40 to 250 m/z and ionized at 70 eV. The separation was performed with a DB5ms capillary column ($60 \text{ m} \times 250 \mu\text{m} \times 1.00 \mu\text{m}$) (Agilent Technologies) at a constant flow ($2 \text{ mL}\cdot\text{min}^{-1}$ He). The oven initial temperature was held at 40°C for 5 min followed by a $7^\circ\text{C}\cdot\text{min}^{-1}$ increase to a final temperature of 250°C that was held for 10 min. Data were collected using the Chemstation G1701 AA (Agilent Technologies). Compounds were first identified by matching mass spectra with library entries (NIST/EPA/NIH Mass Spectral Library, Version 2.0d; National Institute of Standards and Technology, Gaithersburg, MD). The identification of volatile compounds was confirmed using retention indices calculated using retention time data from a series of alkane standards ($\text{C}_5\text{-C}_{17}$) run under the same chromatographic conditions. The relative concentration of volatile compounds was determined by normalizing the peak area of each compound to the peak area of internal standard, and normalized peak areas were compared between samples.

STATISTICAL ANALYSIS. Instrumental and sensory data were analyzed by analysis of variance (ANOVA) with the XLSTAT software (Addinsoft, Paris, France). For sensory data, ANOVAs were performed by harvest date with two factors, genotype and panelist, and panelist as random factor. For instrumental data, ANOVAs were performed by harvest date within genotype and by genotype within harvest date with four replications each time. Separation of means was performed with the Fisher's least significant difference test with $\alpha = 0.05$. Data from the just-right scale were analyzed with the χ^2 test (Meilgaard et al., 1991). Regression analyses were performed for each month between sensory and instrumental variables using the stepwise selection of variables technique. A principal component analysis (PCA) was performed using XLSTAT to

determine a relationship among the variables (TA, SSC, volatile compounds) and the genotypes.

Results and Discussion

SENSORY EVALUATION. In 2006, appearance was rated highest for ‘Festival’, FL 99-164, and FL 01-116 in February and for FL 01-116 and FL 00-51 in March (Table 1A). In 2007, FL 99-164 had high appearance ratings in January and February and ‘Festival’ and FL 01-116 only in February. ‘Rubygem’, a new cultivar from Australia, had high appearance ratings in January and March. FL 00-51 had relatively low ratings for appearance with comments such as “not quite uniform” and “spotty,” which often result from rain damage. ‘Sugarbaby’, another new cultivar from Australia that was evaluated only in Feb. and Mar. 2007, had the lowest appearance ratings for both months.

Texture was rated highest for ‘Festival’ and FL 00-51 throughout the seasons, except in Mar. 2007, with comments such as “good firmness” and “good balance between soft and crunchy” (Table 1B). ‘Rubygem’ also had high texture ratings in the 2007 season with the highest rating in March. In 2006, FL 95-269 had the lowest texture ratings. This selection was considered “too mushy.” In 2007, FL 99-164 had the lowest texture ratings with comments such as “too soft” or “mushy.”

Table 1. Means acceptance scores (1 = dislike extremely; 5 = neither like nor dislike; 9 = like extremely) for appearance, texture, and flavor of strawberry cultivars and selections.

A. Appearance (1–9 scale)					
Cultivar/selection	Feb. 2006	Mar. 2006	Jan. 2007	Feb. 2007	Mar. 2007
Festival	7.8 a ^z	6.8 b	6.2 bc	7.1 a	6.4 ab
00-51	6.5 b	7.5 a	5.9 c	6.4 bc	6.0 b
99-164	7.4 a	7.0 b	7.0 a	7.1 a	6.1 ab
99-117	5.8 c	6.7 b	6.7 ab	6.5 b	6.0 b
01-116	7.4 a	7.6 a	5.9 c	7.5 a	6.1 ab
95-269	5.8 c	5.8 c	—	—	—
Rubygem	—	—	7.0 a	5.9 c	6.6 a
Sugarbaby	—	—	—	5.4 d	5.9 b
B. Texture (1–9 scale)					
Cultivar/selection	Feb. 2006	Mar. 2006	Jan. 2007	Feb. 2007	Mar. 2007
Festival	7.5 a	6.6 a	6.4 b	6.7 ab	6.2 b
00-51	7.3 a	7.1 a	6.9 a	6.9 a	6.2 b
99-164	7.1 ab	6.6 a	5.5 c	5.6 d	5.4 c
99-117	6.0 c	6.7 a	6.6 ab	6.2 c	6.1 b
01-116	6.5 bc	6.8 a	6.4 ab	6.5 abc	6.0 b
95-269	6.2 c	5.6 b	—	—	—
Rubygem	—	—	6.7 ab	6.5 abc	6.7 a
Sugarbaby	—	—	—	6.4 bc	6.3 ab
C. Flavor (1–9 scale)					
Cultivar/selection	Feb. 2006	Mar. 2006	Jan. 2007	Feb. 2007	Mar. 2007
Festival	7.4 a	6.2 b	5.9 bcd	6.9 a	5.2 d
00-51	7.3 a	7.0 a	6.5 a	6.7 a	6.2 ab
99-164	7.2 a	6.5 ab	5.7 d	5.5 c	5.4 cd
99-117	5.5 c	6.5 ab	6.5 ab	5.9 bc	6.0 b
01-116	5.9 bc	6.5 ab	5.9 cd	6.4 ab	4.9 d
95-269	6.2 b	5.3 c	—	—	—
Rubygem	—	—	6.3 abc	6.3 ab	6.7 a
Sugarbaby	—	—	—	6.0 bc	5.9 bc

^zMeans followed by the same letter within column within sensory characteristic were not significantly different by the Fisher’s least significant difference test at $\alpha = 0.05$.

The results for flavor over the two seasons are given in Table 1C. ‘Festival’ had lower ratings in Mar. 2006 and Mar. 2007 than in February of the same years, but also in Jan. 2007. FL 00-51 and ‘Rubygem’ always had high ratings for flavor (above 6) and they had more constant flavor characteristics than other genotypes. Genotypes with low flavor ratings (FL 99-117 in Feb. 2006, FL 95-269 in Mar. 2006, FL 99-164 in January and Feb. 2007, ‘Festival’ and FL 01-116 in Mar. 2007) generally had the lowest sweetness preference ratings in Feb. 2006 (Table 2) and the highest percentage of “not sweet enough” ratings for all other months (Fig. 1), thus clearly linking flavor preference to sweetness perception. This result agrees with the findings reported by Loehndorf et al. (2000) with a trained taste panel. However, in our study, ‘Sugarbaby’ had low flavor ratings in Feb. and Mar. 2007 despite its high percentage of “just right” ratings for sweetness, especially in Mar. 2007. The analysis of volatile compounds may explain the dislike for ‘Sugarbaby’ and is discussed under “Relating sensory to instrumental data.”

The chemical composition of each selection was determined to help interpret the sensory data and to link harvest date and/or genotype with SSC, TA, and specific volatile compounds.

SOLUBLE SOLIDS CONTENT AND TITRATABLE ACIDITY. Among the selections evaluated across the two harvest seasons, FL 00-51 and FL 99-117 had relatively high SSC in 2006 and 2007 (Table 3A) (letters in lowercase). However, ‘Sugarbaby’, the new cultivar evaluated in 2007, exceeded the SSC found in all other genotypes. ‘Rubygem’ had SSC similar to FL 00-51 in 2007. There was a great seasonal variation for SSC for all genotypes (letters in uppercase). In 2006, SSC was affected by the harvest date for FL 00-51 and FL 01-116, whereas it remained constant for ‘Festival’, FL 99-117, FL 95-269, and FL 99-164. In 2007, all selections had a higher SSC in February than in March and January. A recent study on SSC in strawberry grown in Florida showed that rising temperatures were responsible for the decline in SSC at the end of the growing season (MacKenzie and Chandler, 2008). In Jan. and Mar. 2007, the average temperatures of the week before the harvest date were 20.0 and 20.6 °C, respectively, whereas in Feb. 2007, the average temperature was 14.5 °C according to the Florida Automated Weather Network (University of Florida, 2008). Higher temperatures in January and March might explain the relatively low SSC both months. In Feb. and Mar. 2006, the average temperatures were 16.1 and 17.2 °C, respectively (University of Florida, 2008), and the SSC did not vary much between both months except for FL 00-51.

Table 2. Mean acceptance scores (1 = dislike extremely; 5 = neither like nor dislike; 9 = like extremely) for sweetness and tartness of six strawberry cultivars and selections in Feb. 2006.

Cultivar/selection	Sweetness (1–9 scale)	Tartness (1–9 scale)
Festival	7.0 a ^z	6.6 a
00-51	7.1 a	6.5 a
99-164	6.8 a	6.3 a
01-116	5.5 b	5.3 b
99-117	5.6 b	5.0 b
95-269	5.5 b	5.4 b

^zMeans followed by the same letter within a column were not significantly different by the Fisher's least significant difference test at $\alpha = 0.05$.

As shown in Table 3B, FL 99-117 generally exhibited the highest and 'Sugarbaby' the lowest TA throughout the season. These results are consistent with the findings of Shaw (1988) who found that the relative expression of acids was stable throughout the evaluation period, which was in the spring, in Watsonville, CA. However, in this study, the TA of all the genotypes varied considerably from harvest date to harvest

date: Feb. 2006 produced strawberries with the most elevated TA except for 'Festival', thus highlighting a possible harvest date effect.

VOLATILE COMPOUNDS. The aroma profile did not vary qualitatively but only quantitatively among genotypes. This result is consistent with the fact that all genotypes were bred from the cultivated species *F. ×ananassa*. This species is mostly characterized by the lack of methyl anthranilate, which gives the unique flavor of wild species (Ulrich et al., 1997, 2007). Moreover, the terpenoid profile of *F. ×ananassa* is dominated by linalool and nerolidol, whereas monoterpenes such as α -pinene and β -myrcene are mainly produced by wild species (Aharoni et al., 2004).

Table 4 shows the relative concentrations of volatile compounds in 'Festival' (the industry standard) and FL 00-51 (the most promising selection in terms of flavor) in Mar. 2006. Sixty-eight volatile compounds were identified from the SPME extracts. The aroma profile was dominated by esters followed by alcohols/aldehydes, terpenoids, and lactones. Despite the addition of CaCl_2 to reduce the enzymatic activity of lip-oxygenase, significant amounts of n-hexanal and (*E*)-2-hexenal were formed during the fruit preparation through the action of this enzyme on unsaturated fatty acids (Sanz et al., 1997).

Although the content of C6 aldehydes depends on cultivars and ripening stage, sample preparation may affect the content of these compounds even more (preliminary data, not shown). We allowed 1 min before adding CaCl_2 to account for the time when a person masticates fruit. That may have been too much because these "green" compounds may only account for less than 0.1% of volatiles collected from whole fruit (Ito et al., 1990). Furanones (furanol and mesifurane) were detected in a small amount because the headspace techniques are not the best methods to collect them. Pérez et al. (1996) and Sanz et al. (1994) found a better recovery of these compounds from liquid extracts analyzed by high-performance liquid chromatography. Nevertheless, headspace sampling remains the best compromise to analyze most other volatiles.

The relative concentrations of esters, aldehydes/alcohols, and terpenoids were not significantly different between 'Festival' and FL 00-51. However, 'Festival' had elevated contents of ethyl-2-methylbutanoate and ethyl esters, and FL 00-51 contained more octyl and butyl esters than 'Festival'. The content of lactones was significantly higher in fruit of FL 00-51 than in fruit of 'Festival'. However, these compounds, especially γ -decalactone, could not explain the better score

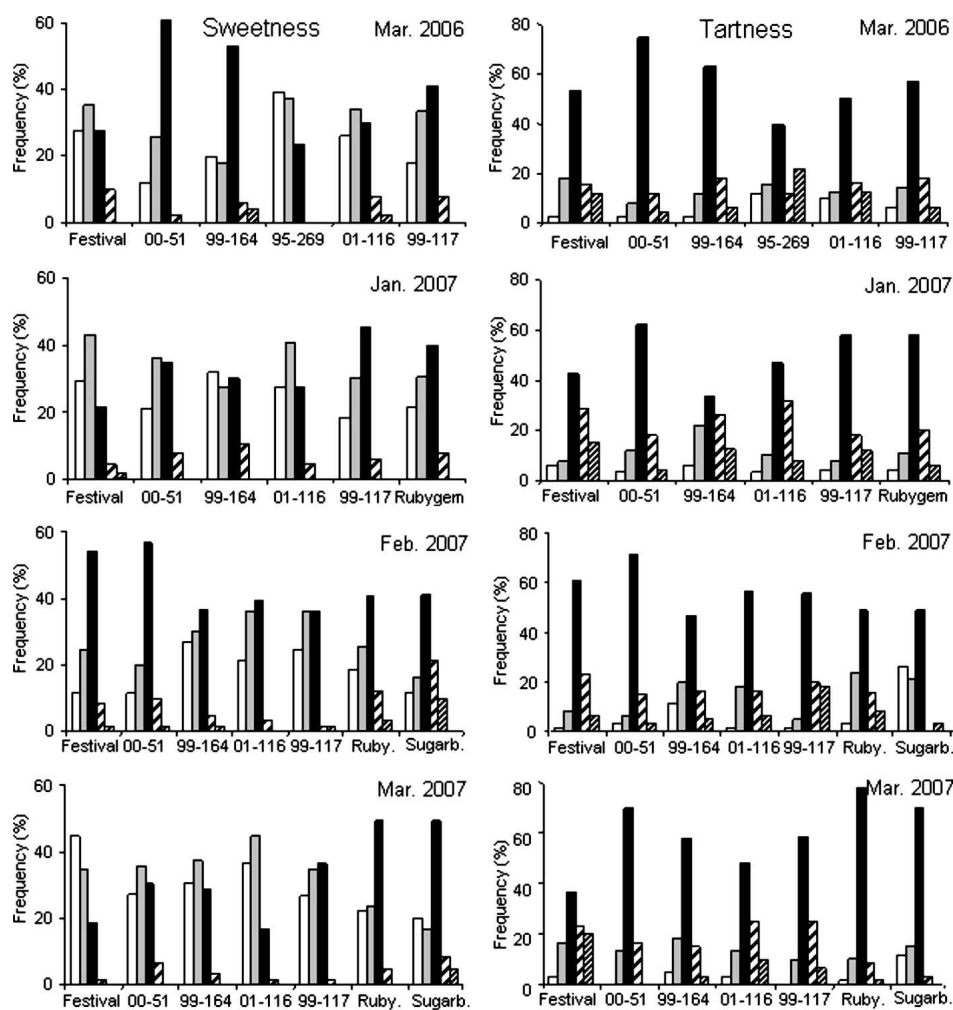


Fig. 1. Percentage of panelists rating sweetness and tartness of strawberry selections on a 5-point just-right scale: □ and ■ not sweet/sour enough (1 and 2), ■ just right (3), ▨ and ▩ too sweet/sour (4 and 5); Ruby = 'Rubygem', Sugarb = 'Sugarbaby'.

Table 3. Soluble solids content (SSC) and titratable acidity (TA) of strawberry cultivars and selections over the two harvest seasons.

A. SSC (%)					
Cultivar/selection	Feb. 2006	Mar. 2006	Jan. 2007	Feb. 2007	Mar. 2007
Festival	7.5 b B ^c	7.5 b B	6.9 b C	9.8 b A	6.2 c D
00-51	10.2 a A	8.2 a C	7.7 a CD	9.6 b B	7.3 b D
99-164	7.9 b AB	7.5 b B	6.7 b C	8.3 c A	6.2 c C
99-117	8.0 b BC	8.3 a B	7.7 a CD	9.9 ab A	7.2 b D
01-116	6.5 c B	7.9 ab A	6.6 b B	8.5 c A	5.3 d C
95-269	6.8 c A	6.5 c A	—	—	—
Rubygem	—	—	7.4 a B	9.3 b A	7.1 b B
Sugarbaby	—	—	—	10.5 a A	8.4 a B
B. TA (g·L ⁻¹)					
Cultivar/selection	Feb. 2006	Mar. 2006	Jan. 2007	Feb. 2007	Mar. 2007
Festival	7.51 c B	6.26 bc C	9.12 a A	8.71 ab A	7.34 ab B
00-51	9.15 b A	5.83 c D	7.84 b B	7.12 c C	6.85 bc C
99-164	9.00 b A	5.90 c C	7.55 b B	7.33 a B	7.10 abc B
99-117	10.24 a A	6.69 ab D	9.52 a B	9.34 a B	7.91 a C
01-116	8.77 b A	7.04 a B	8.08 b AB	8.40 b A	6.76 bc B
95-269	9.00 b A	6.50 abc B	—	—	—
Rubygem	—	—	7.59 b A	7.41 c A	6.31 cd B
Sugarbaby	—	—	—	5.90 d A	5.79 d A

^aMeans followed by the same letter within column within measurement (lowercase) and within row (uppercase) were not significantly different by the Fisher's least significant difference test at $\alpha = 0.05$.

for flavor of FL 00-51, because FL 01-116 and FL 99-117 were rated equal in flavor to FL 00-51 but had the same lactone content as 'Festival' (data not shown); thus, lactones were not solely responsible for the better flavor of FL 00-51. Generally, there were no meaningful and reproducible correlations between individual volatile compounds and flavor preference across the two seasons. Therefore, compounds were grouped by chemical class for further analysis.

Table 5 gives the relative concentration of esters, alcohols/aldehydes, terpenoids, and lactones of the strawberry genotypes over the two seasons. FL 99-117, FL 99-164, and FL 00-51 had high ester contents except for FL 99-164 in Feb. 2006 and FL 00-51 in Jan. 2007 (Table 5A). 'Sugarbaby' harvested in Feb. and Mar. 2007 contained 15 and 40 times less esters than the other genotypes harvested at this time. The ester contents of all genotypes were highly affected by harvest date. Similar findings were reported by Forney et al. (2000) and by Pelayo-Zaldívar et al. (2005). In our study, fruit with the highest ester levels were found in Mar. 2006 and lowest levels from fruit harvested in Jan. 2007. Aldehydes/alcohols content did not vary much among the genotypes and harvest date had little effect on this group of compounds (Table 5B). FL 01-116 and FL 99-117 generally had the highest terpenoid content (Table 5C). Harvest date played a significant role in the terpenoid content of most genotypes except for possibly 'Rubygem' and 'Sugarbaby'. The highest terpenoid content was in fruit harvested in Feb. 2007 and the lowest was found in Feb. 2006. High lactone contents were found in FL 99-164 at every harvest date and in FL 00-51 in Feb. 2006 and Mar. 2007. 'Sugarbaby' had the lowest lactone contents (Table 5D). In Feb. 2007, most selections contained high lactone levels except 'Sugarbaby' and 'Festival'.

RELATING SENSORY TO INSTRUMENTAL DATA. SSC and TA data explained sweetness and tartness preference ratings most of the time. Indeed, genotypes judged as "not sweet enough" for sweetness preference often had a low SSC. In Feb. 2006, FL 95-269 and FL 01-116 had the lowest SSC and the lowest

sweetness preference ratings (Table 2). FL 99-117 was also rated with a low score for sweetness, but its SSC was not different from the SSC of genotypes with high scores (FL 99-164 and 'Festival'). However, its TA was significantly higher than that of all genotypes (Table 3B), thus inducing a perception of lack of sweetness ("not sweet enough" ratings). In Mar. 2006, the low SSC of FL 95-269 could explain the lack of sweetness perceived by the panelists (Fig. 1). In Jan. 2007, 'Festival', FL 99-164, and FL 01-116, clearly judged as "not sweet enough," had the lowest SSC. In the same way, the elevated TA of 'Festival' was associated with higher ratings for "too sour." In Mar. 2007, the low SSC of FL 01-116 and 'Festival' were also associated with low sweetness "just right" ratings. Generally, SSC seemed to be a good indicator for sweetness preference. In a previous study, Sims et al. (1997) found a good agreement between SSC/TA and sweetness evaluated by a trained panel. However, in our study, in Feb. 2007, FL 99-117, which had an elevated SSC similar to 'Festival', was evaluated as "not sweet enough" by most panelists. Its TA was not significantly different from that of 'Festival' (they had similar SSC/TA), but 'Festival' had a high percentage of "just-right" ratings for sweetness. In this case, SSC and SSC/TA were not the only variables affecting sweetness preference. The main contribution to SSC in strawberry is from sugars followed by organic acids and soluble pectins (Pelayo-Zaldívar et al., 2005), but in Feb. 2007, other compounds such as astringent tannins or nonvolatile acids may have altered sweetness perception for FL 99-117.

To help explain the eating quality of the genotypes, a multiple regression was carried out to predict flavor liking with volatiles, SSC, TA, and SSC/TA (Table 6). When significant, the models included either SSC or SSC/TA. In Feb. 2006, SSC/TA was the variable retained in the model by the stepwise selection with an R^2 of 0.727. In Mar. 2006 and Jan. 2007, SSC was the variable retained in the regression models with R^2 of 0.827 and 0.893, respectively. In Feb. and Mar. 2007, lactones

Table 4. Relative concentration of volatile compounds in 'Festival' and FL 00-51 in Mar. 2006.^z

No.	Compounds	RI ^y	Festival	FL 00-51	No.	Compounds	RI	Festival	FL 00-51
1	Methyl acetate	528	0.286	0.065	36	Hexyl acetate	1010	0.313	0.638
2	Ethyl acetate	604	1.565	0.059	37	(<i>E</i>)-2-hexenyl acetate	1012	0.377	0.230
3	Methyl propanoate	622	0.016	0.000	38	Isopropyl hexanoate	1033	0.064	0.108
4	Isopropyl acetate	653	0.029	0.003	39	Ethyl-2-hexenoate	1044	0.041	0.004
5	Ethyl propanoate	707	0.078	0.000	40	d-limonene	1045	0.106	0.101
6	Methyl butanoate	720	0.945	0.944	41	Amyl butyrate	1055	0.036	0.036
7	(<i>E</i>)-2-pentenal	757	0.031	0.016	42	Furaneol ^x	1054	0.005	0.000
8	Butanoic acid	768	0.031	0.015	43	Heptanoic acid	1055	0.000	0.000
9	Methyl isovalerate	778	0.000	0.030	44	Mesifurane ^w	1062	0.258	0.062
10	3-hexanone (IS)	787	1	1	45	Propyl hexanoate	1091	0.028	0.012
11	Ethyl butyrate	801	2.525	1.207	46	Linalool	1104	0.216	0.456
12	n-hexanal	804	0.432	0.619	47	Nonanal	1108	0.020	0.024
13	Butyl acetate	814	0.100	0.364	48	Methyl octanoate	1121	0.052	0.039
14	Methyl pentanoate	826	0.008	0.019	49	Octanoic acid	1151	0.079	0.049
15	2-methyl butanoic acid	838	0.000	0.048	50	Ocimenol	1168	0.085	0.000
16	Isopropyl butanoate	842	0.177	0.116	51	Benzyl acetate	1171	0.089	0.104
17	Ethyl 2-methylbutanoate	851	0.558	0.034	52	Ethyl benzoate	1183	0.034	0.002
18	Ethyl 3-methylbutanoate	856	0.066	0.078	53	Butyl hexanoate	1186	0.032	0.311
19	(<i>E</i>)-2-hexenal	862	2.268	2.107	54	Ethyl octanoate	1189	0.282	0.032
20	(<i>E</i>)-2-hexen-1-ol	868	0.046	0.014	55	Octyl acetate	1204	0.095	0.278
21	1-hexanol	871	0.000	0.018	56	α -terpineol	1214	0.243	0.104
22	Isoamyl acetate	878	0.055	0.082	57	Isoamyl hexanoate	1245	0.000	0.022
23	2-methylbutyl acetate	880	0.107	0.000	58	Nonanoic acid	1248	0.019	0.002
24	2-heptanone	894	0.009	0.055	59	Octyl butyrate	1383	0.052	0.858
25	Propyl butyrate	899	0.075	0.024	60	Ethyl decanoate	1388	0.022	0.010
26	Ethyl pentanoate	901	0.032	0.018	61	Decyl acetate	1401	0.005	0.030
27	2-heptanol	904	0.000	0.021	62	Octyl isovalerate	1434	0.011	0.171
28	Amyl acetate	914	0.019	0.020	63	β -farnesene	1455	0.019	0.004
29	(<i>E,E</i>)-2,4-hexadienal	917	0.048	0.058	64	γ -decalactone	1483	0.026	0.478
30	Methyl hexanoate	926	1.244	1.790	65	α -farnesene	1507	0.000	0.000
31	Hexanoic acid	969	0.245	0.334	66	(<i>E</i>)-nerolidol	1570	0.446	0.234
32	Benzaldehyde	981	0.022	0.009	67	Octyl hexanoate	1580	0.041	0.342
33	Butyl butyrate	996	0.066	0.617	68	Decyl butyrate	1584	0.005	0.045
34	Ethyl hexanoate	998	3.121	2.051	69	γ -dodecalactone	1704	0.053	0.028
35	(<i>Z</i>)-3-hexenyl acetate	1005	0.163	0.084					
	Sum of esters							12.811 a	10.876 a
	Sum of alcohols/aldehydes							2.930 a	2.876 a
	Sum of terpenoids							0.924 a	0.798 a
	Sum of lactones							0.078 b	0.505 a

^zResults represent means of three or four replications calculated as relative concentrations related to 3-hexanone (IS) ($1 \mu\text{L}\cdot\text{L}^{-1}$, v/v); Means followed by the same letter within row were not significantly different by the Fisher's least significant difference test at $\alpha = 0.05$.

^yRI = retention indices.

^x2,5-dimethyl-4-hydroxy-3(2H)-furanone.

^w2,5-dimethyl-4-methoxy-3(2H)-furanone.

and SSC were entered in the model, respectively, but neither model was significant. As shown in Table 6, no class of volatiles explained flavor preference. Indeed, in Jan. 2007, FL 99-164 was not liked by the panelists (Table 1C) but had high contents of esters and lactones (Table 4). On the contrary, 'Rubygem' was appreciated by the panelists despite its lower ester content. In Feb. 2007, 'Rubygem' and FL 01-116 contained relatively low ester levels but had high scores for flavor preference. In March, 'Rubygem' had high flavor ratings, but its aroma profile was similar to that of 'Festival', which was not liked by the panelists. Similar conclusions could be drawn for the 2006 season, that is, flavor acceptance was not influenced by volatile content. In general, SSC and/or SSC/TA were good indicators of flavor liking. This result agrees with

the findings of other authors (Pelayo-Zaldívar et al., 2005; Shamailla et al., 1992; Wozniak et al., 1997). However, in this study, SSC and/or SSC/TA did not explain the flavor liking of 'Sugarbaby'. This cultivar was disliked by most panelists despite its high sugar content. In the comments, they indicated "very sweet," but it tastes "artificial," like "peach," "apricot," "blueberry." The imbalance of its volatile profile, with extremely low ester content, might explain low flavor ratings. Moreover, the lack of esters could make lactones more perceived by the panelists and that might explain peachy notes in comments. This result highlights the role of esters in strawberry flavor and indicates that a good balance between esters and sugars is important for the overall acceptability of strawberry. In this study, ester contents were high enough in all

Table 5. Relative concentration of esters, alcohols/aldehydes, terpenes, and lactones of strawberry cultivars and selections over the two seasons.^z

A. Esters					
Cultivar/selection	Feb. 2006	Mar. 2006	Jan. 2007	Feb. 2007	Mar. 2007
Festival	9.91 a B ^y	12.81 a A	3.20 bc C	3.58 bcd C	3.17 c C
00-51	12.37 a A	10.88 a A	3.31 bc C	6.38 a B	7.35 a B
99-164	6.30 b B	12.34 a A	4.34 ab C	5.77 ab BC	6.11 ab B
99-117	10.84 a A	9.91 ab AB	5.36 a C	4.44 abc C	7.76 a B
01-116	3.48 b BC	12.15 a A	2.38 c BC	2.62 de C	4.24 bc B
95-269	5.00 b B	7.16 b A	—	—	—
Rubygem	—	—	2.43 c B	3.16 cd AB	3.58 bc A
Sugarbaby	—	—	—	0.16 e B	0.46 d A
B. Aldehydes/alcohols					
Cultivar/selection	Feb. 2006	Mar. 2006	Jan. 2007	Feb. 2007	Mar. 2007
Festival	2.08 b C	2.93 a AB	2.58 a BC	3.40 ab A	2.54 b BC
00-51	3.18 a A	2.88 a AB	1.91 b B	2.72 b AB	3.71 a A
99-164	3.18 a A	2.43 ab B	2.52 a B	3.12 ab A	2.34 b B
99-117	2.89 a A	1.90 b B	2.05 ab B	3.52 a A	3.13 ab A
01-116	2.22 b B	2.39 ab B	2.31 ab B	3.17 ab A	3.35 ab A
95-269	2.04 b A	2.32 ab A	—	—	—
Rubygem	—	—	2.43 ab B	3.15 ab AB	3.47 ab A
Sugarbaby	—	—	—	2.79 b B	3.93 a A
C. Terpenes					
Cultivar/selection	Feb. 2006	Mar. 2006	Jan. 2007	Feb. 2007	Mar. 2007
Festival	0.05 c C	0.92 b B	0.95 bc B	1.34 c A	0.70 de B
00-51	0.07 bc C	0.80 b B	0.57 c BC	1.92 bc A	1.02 cd B
99-164	0.13 a C	0.77 b B	1.34 ab A	1.68 c A	0.32 e C
99-117	0.12 ab C	1.14 ab B	0.96 bc B	2.89 ab A	2.17 a A
01-116	0.11 abc C	1.48 a B	1.76 a B	3.64 a A	1.70 ab B
95-269	0.07 bc B	1.33 a A	—	—	—
Rubygem	—	—	1.24 ab A	1.89 bc A	1.13 cd B
Sugarbaby	—	—	—	1.26 c A	1.40 bc A
D. Lactones					
Cultivar/selection	Feb. 2006	Mar. 2006	Jan. 2007	Feb. 2007	Mar. 2007
Festival	0.06 b B	0.08 c B	0.07 b B	0.03 d C	0.11 d A
00-51	0.97 a AB	0.51 b BC	0.33 b C	1.14 b A	1.08 a A
99-164	0.89 a BC	1.33 a B	0.88 a BC	2.20 a A	0.67 ab C
99-117	0.07 b B	0.08 c B	0.09 b B	0.66 c A	0.19 cd B
01-116	0.16 b C	0.12 c C	0.42 b BC	1.14 b A	0.75 ab B
95-269	0.05 b A	0.06 c A	—	—	—
Rubygem	—	—	0.36 b B	0.89 bc A	0.59 bc AB
Sugarbaby	—	—	—	0.03 d B	0.09 d A

^zEach number is the sum of relative volatile concentration in each chemical class and average of four replications.

^yMeans followed by the same letter within column (lowercase) of each volatile class and within row (uppercase) were not significantly different by the Fisher's least significant difference test at $\alpha = 0.05$.

selections throughout the seasons (except in 'Sugarbaby') and sugar content was the discriminating parameter.

GENOTYPE AND HARVEST SEASON EFFECTS ON CHEMICAL COMPOSITION. To see the relationship between selections and volatiles, TA, SSC, and SSC/TA, a PCA was performed on the 2006 and 2007 data.

Figure 2 shows the representation of selections and quantitative variables on the first two dimensions of the PCA. Principal components 1 and 2 (F1 and F2) accounted for 27% and 21% of the variation, respectively. F1 could be defined as a combination of SSC, SSC/TA, and lactones on the positive side

Table 6. Statistical summary of stepwise multiple regressions of instrumental data to predict consumer acceptability for each month.

Month	Variable ^z	R ²	F value
Feb. 2006	SSC/TA	0.727	10.63*
Mar. 2006	SSC	0.827	19.10*
Jan. 2007	SSC	0.893	33.54**
Feb. 2007	Lactones	0.219	1.80 NS
Mar. 2007	SSC	0.516	5.32 NS

^zSSC = soluble solids content; SSC/TA = soluble solids content/titratable acidity ratio.

NS, *, **Nonsignificant or significant at 5% and 1% levels, respectively.

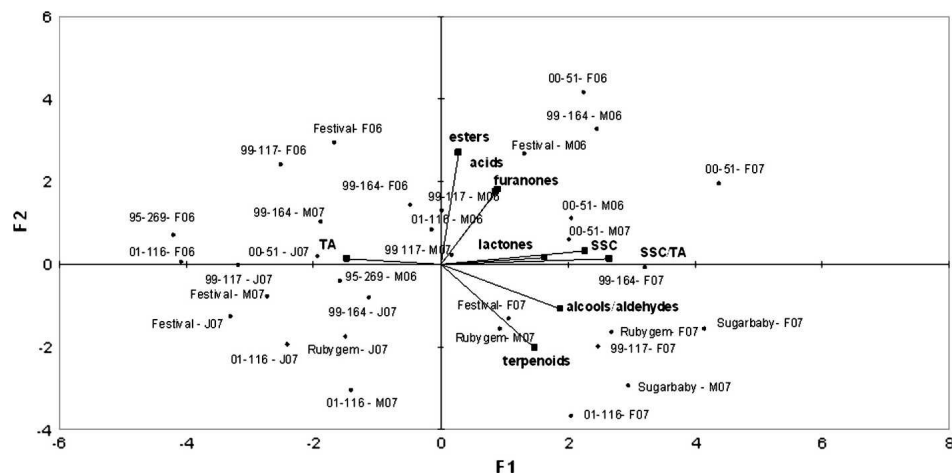


Fig. 2. Principal component analysis plot of selections/month and variables (sum of relative peak areas of esters, aldehydes/alcohols, terpenoids, acids, lactones, furanones = volatiles compounds; TA = titratable acidity; SSC = soluble solids content; SSC/TA = SSC/TA ratio). Principal components 1 (F1) and 2 (F2) account for 27% and 21% of the variation, respectively; F06 = Feb. 2006, M06 = Mar. 2006, J07 = Jan. 2007, F07 = Feb. 2007, M07 = Mar. 2007.

and TA on the negative side. F2 was mostly defined by esters. The results indicate that the aroma profile of the selections mainly depended on the harvest date except for FL 00-51. In Feb. 2006, fruit were characterized by a low content of terpenoids and alcohols/aldehydes, but had high TA; they are grouped in the upper left quadrant on Figure 2. In Mar. 2006, fruit had a high content of esters, acids, furanones, and lactones and high SSC and SSC/TA and are grouped in the upper right of the quadrant on Figure 2. Selection FL 95-269 was an exception, having a low SSC and a low level of volatiles in Mar. 2006, and it also had the lowest flavor rating during sensory evaluation. Jan. 2007 produced fruit with low volatile content and SSC (lower left quadrant) and Feb. 2007 produced fruit with high terpenoids and alcohols/aldehydes contents and also high SSC and lactone content (lower right quadrant). FL 00-51 was an exception to this distribution because its fruit were always characterized by a high level of volatiles (esters, acids, and furanones) and a high SSC (except for Jan. 2007). This is in agreement with the elevated panel ratings for flavor and sweetness for FL 00-51. In Mar. 2007, chemical composition varied according to genotype. However, genotypes with the lowest flavor and sweetness preference ratings in Mar. 2007 ('Festival' and FL 01-116) showed low volatile contents and SSC like the "January selections." A final observation is that volatile content, like TA and SSC, was greatly affected by harvest date (i.e., environment and genotype \times environment interactions). Unlike SSC, lower temperatures in Feb. 2007 only had effect on terpenes and lactones, higher in fruit harvested that month (Table 5). Esters were similar in Jan. and Feb. 2007, and aldehydes/alcohols were similar in Feb. and Mar. 2007 despite noticeable temperature differences among all 3 months. In addition to environmental effects on volatile and SSC/TA composition, harvest maturity may not be exactly identical for all fruit and at each harvest under a commercial setting. This would also explain seasonal differences between fruit chemical quality (Forney et al., 2000). Nevertheless, the consistency of high SSC and high volatile content of FL 00-51 over the season made this selection stand out among others.

The sensory evaluation over two seasons showed high variation among strawberry genotypes grown in Florida in

terms of flavor, sweetness, and tartness preferences. Higher strawberry SSC or SSC/TA were preferred by panelists, except for 'Sugarbaby', which had high SSC but low ester content and low strawberry-like flavor ratings. FL 00-51 and 'Rubygem', which contained high sugar level, were the most preferred genotypes, but 'Rubygem' needs to be evaluated over another season to confirm these 2007 results. Our study shows that aroma volatiles and sugar levels must be balanced to ensure a flavor appealing to consumers. Although germplasm strongly influenced volatile composition and perceived flavor, harvest date was also found to be an important factor influencing strawberry composition.

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