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Effect of Harvest Date on the Soluble Solids Content and Sugar Profile of Commercial Strawberry Cultivars and Advanced Selections from the University of Florida

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The objectives of this study were to compare strawberry cultivars and advanced breeding selections from the University of Florida for soluble solids (SSC), glucose, fructose, and total sugar (TS) contents and to examine the influence of harvest date throughout the 2011–12 strawberry season. Winterstar™ FL 05-107, 'Strawberry Festival', 'Florida Radiance', and four advanced selections FL 06-38, FL 07-193, FL 09-127 and FL 10-47 were evaluated on four harvest dates from January to February 2012. The high field temperatures measured in late-February seemed to have contributed to a reduced SSC for all genotypes. Selections FL 06-38, FL 09-127, and FL 10-47 showed a constant decrease in TS from late-January to late-February. In comparison, FL 07-193 showed a constant TS content throughout those harvest dates, although it experienced a significant decrease in the TS content in the mid-January harvest. Overall, strawberry genotypes seemed to respond to seasonal field temperatures differently. FL 09-127 was ranked as either the first or second genotype for TS content on all dates when it was measured. This suggests that this genotype may have consistently good eating quality. 'Florida Radiance' showed more variation in TS than some other genotypes across harvest dates.

Strawberries (*Fragaria ×ananassa* Duchesne) are one of the major fresh market commodities produced in Florida, with a harvested area of approximately 10,000 acres and production value estimated at $366 million dollars during the 2010–11 crop production year (USDA NASS, 2012). Florida strawberries traditionally are the earliest berries on the U.S. market, harvested from late-November to the end of March. 'Strawberry Festival' is a grower favorite, particular due to its long shelf-life (Crocker and Chandler, 2000). It has been the major cultivar grown in west-central Florida, comprising over half of the planted acreage during the 2010–11 season (Whitaker et al., 2011), though 'Florida Radiance' emerged as the new leading cultivar in 2011–12. The newest commercial cultivar, Winterstar™ 'FL 05-107', was released in 2011 and is grown on small acreage (Whitaker et al., 2012).

Temperatures in central Florida in January average approximately 15 °C and growers cease harvesting fruit in late-March when the average daily temperatures reaches approximately 21 °C (Mackenzie and Chandler, 2009). The developmental stage of the strawberry plant in combination with higher temperatures at the end of the season appear to contribute to the decline of soluble solids content in most seasons (Mackenzie and Chandler, 2009; Wang and Camp, 2000).

Sugars contribute to the flavor characteristics of strawberry, and the amount present will contribute to the likability of the fruit (Jouquand et al., 2008; Maas et al., 1996). According to Wroldstad and Shallenberger (1981) and Strum et al. (2003), sucrose, glucose, and fructose represent more than 99% of the total sugars in ripe strawberry fruit. Glucose and fructose are present in approximately equal concentrations (Maas et al., 1996). However, when ripening progresses, a decrease of sucrose content and an increase of glucose and fructose occur (Ferreyra et al., 2007; Montero et al., 1996; Strum et al., 2003). Environmental differences as well as cultivar-specific characteristics can contribute to the variability in sugar content (Haila et al., 1992; Shamaila et al., 1992; Strum et al., 2003; Wroldstad and Shallenberger, 1981).

The objectives of this study were to compare strawberry cultivars and advanced breeding selections from the University of Florida for soluble solids (SSC), glucose, fructose, and total sugar (TS) contents and to examine the influence of harvest date on these variables throughout the 2011–12 season. Although limited amounts of fruit were available for most advanced selection trials, it is important from a breeding perspective to determine if genotypes can be statistically separated from one another for the attributes previously mentioned when only small samples of fruit are available for testing.

Materials and Methods

Plant material. Strawberries were grown at the Gulf Coast Research and Education Center (GCREC) of the University of Florida at Balm, FL during the 2011–12 strawberry season. The trials at the GCREC were planted on two-row raised beds covered with black polyethylene mulch. A mixture of telone (65%) and chloropicrin (35%) was used to fumigate beds prior to planting in October. The following genotypes were evaluated: Winterstar™ 'FL 05-107', 'Florida Radiance', 'Strawberry Festival', FL 06-38, FL 07-193, FL 09-127, and FL 10-47. Four replicated plots (10 plants per plot) of each genotype were planted in a randomized complete-block design at the GCREC on Oct. 2011. Twenty

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fully-ripe marketable berries were hand harvested early in the morning on 16 Jan. (mid-January), 30 Jan. (late-January), 13 Feb. (mid-February). and 27 Feb. (late-February) 2012, packed in 1-lb vented clamshells (Wasserman Bag Co., Inc., Hicksville, NY), and transported at ambient temperature to the University of Florida, Gainesville, within 2 h. A representative sample of marketable fruit (five berries per clamshell) was retained for the chemical analyses across the four harvest dates.

Chemical analysis. Five strawberry fruit per genotype were homogenized in a laboratory blender at high speed for 2 min, poured in 50-mL plastic tubes and kept frozen at –34 °C until analyzed. Fruit chemical analyses for 2011–12 samples were conducted at the University of South Florida, Food Quality Laboratory in Tampa, FL.

Soluble solids content (SSC). The homogenates were thawed and centrifuged at 12,000 rpm for 20 min and filtered through cheesecloth. SSC of the supernatant was determined by placing 0.3 mL of juice onto the prism surface of a digital ATAGO PR-101 refractometer in the 0% to 45% SSC range (Atago Co., Tokyo, Japan). The refractometer was calibrated using deionized water.

Sugar content. Frozen samples were thawed at 4 °C overnight and 2 g of fruit puree were combined with 8 mL of ultrapure water (Ω18-17) and then centrifuged at 6,000 rpm for 10 min. The obtained supernatant was filtered through a 0.45-µm nylon filter into 2-mL labeled vials. Samples were prepared and run in triplicate. The HPLC quantification of individual sugars was conducted using a Hitachi HPLC system with a RI– refractive index detector and a 300 mm × 8 mm Shodex SP0810 column (Shodex, Colorado Springs, CO) with a SP-G guard column (2 mm × 4 mm). Isocratic solvent delivery of water was set at 1.0 mL·min^{-1}. Sample injection volume was 5 µL. Standard solutions of sucrose, glucose, and fructose (Fisher Scientific Company, Pittsburgh, PA) were used to identify sample peaks. The peaks were identified by comparing retention times with those of the standards. The amount of total sugars in strawberry was quantified using calibration curves obtained from different concentrations (2, 4, 6, 10, and 20 mg·mL^{-1}) of sucrose, glucose, and fructose standards. Three samples per genotype (2 g fruit puree) were used, each with duplicate HPLC injections. Total sugar and individual sugar contents were expressed in g·100 g^{-1} fresh weight.

Statistical analysis. Analyses of variance (ANOVA) were performed using general linear models with genotype, harvest date, and the genotype × harvest date interaction as fixed effects using SAS® software (version 9.3; SAS Institute Inc., Cary, NC). When the genotype × harvest date interactions were significant (F-test, $P \leq 0.05$), the data were analyzed separately by harvest date. Significant differences among the genotypes within harvest dates and within the same genotype across harvest dates were detected using Fisher's protected least significant difference (LSD) test at $P \leq 0.05$.

Results and Discussion

A significant genotype × harvest date interaction ($P \leq 0.001$) for TS is shown in Table 1.There were significant differences among strawberry genotypes for TS content evaluated across the four harvest dates during the 2011–12 strawberry season (Table 1). Selections FL 06-38, FL 09-127, and FL 10-47 exhibited a constant decrease in TS from late-January to late-February. In comparison, FL 07-193 showed constant TS throughout the same harvest dates, though it had experienced a significant decrease in TS in the mid-January harvest, and TS was generally lower than the advanced selections previously mentioned late-January and thereafter. 'Strawberry Festival' also exhibited a constant decrease over the 2 months.

Significant genotype × harvest date interactions ($P \leq 0.001$) for SSC are shown in Table 2. There were significant differences among strawberry genotypes for SSC evaluated across the four harvests during the 2011–12 strawberry season (Table 2). In mid-January, selection FL 07-193 had the highest SSC followed by Winterstar™ FL 05-107. Selection FL 09-127 harvested in late-January had the highest SSC among all strawberry cultivars and advanced breeding selections.

Significant genotype × harvest date interactions ($P \leq 0.001$) for fructose and glucose are shown in Tables 3 and 4, respectively. Winterstar™ FL 05-107, 'Strawberry Festival' and selection FL 07-193 harvested in mid-January had the highest glucose content 2.91, 3.07, and 3.08 g·100 g^{-1}, respectively (Table 4). Selections FL 09-127 and FL 06-38 harvested during late-January showed the highest glucose content among cultivars, which were 2.80 and 2.73 g·100 g^{-1}, respectively. From late-January to late-February a constant decrease of glucose content occurred for selections FL 06-38, FL 09-127, and FL 10-47. However, a drop in temperature during the mid-February harvest (Table 5) may explain the increase of glucose content observed in Winterstar™ FL 05-107, selection FL 07-193, and 'Florida Radiance'. Fructose content of FL 06-

Table 1.Total sugars of strawberry commercial varieties and University of Florida advanced selections measured on four harvest dates during the 2011–12 strawberry season.

	Total sugars (g·100 g^{-1})			
Genotype	Mid-January	Late January	Mid-February	Late February
Winterstar™ FL 05-107	6.09 A[z]b[y]	3.08 Cg	4.20 Be	2.62 Df
FL 06-38	---[x]	6.44 Aa	4.97 Bb	4.63 Cb
FL 07-193	6.39 Aa	3.65 Be	3.69 Bf	3.66 Bd
FL 09-127	---	5.80 Ab	5.21 Ba	4.80 Ca
FL 10-47	---	4.80 Ac	4.42 Bd	3.49 Ce
'Strawberry Festival'	5.85 Ac	4.06 Bd	4.16 Ce	3.80 Dc
'Florida Radiance'	5.24 Ad	3.35 Cf	4.49 Bc	---
P-value (genotype)	<0.0001	<0.0001	<0.0001	<0.0001
P-value (harvest date)		<0.0001		
P-value (harvest date × genotype)		<0.0001		

[z]Mean separations as uppercase within rows by LSD test at $P \leq 0.05$.
[y]Mean separations as lowercase within columns by LSD test at $P \leq 0.05$.
[x]Least squares means not estimable resulting from missing samples due to low yield or unbalanced replication.

Table 2. Soluble solids content of strawberry commercial varieties and University of Florida advanced selections measured on four harvest dates during the 2011-12 strawberry season.

	Soluble solids content (%)			
Genotype	Mid-January	Late January	Mid-February	Late February
Winterstar™ FL 05-107	8.40 A[z]b[y]	7.40 Bb	6.37 De	6.60 Ca
FL 06-38	---[x]	7.20 Ac	6.57 Bd	5.80 Cd
FL 07-193	8.87 Aa	6.10 Bg	6.10 Bf	5.90 Cc
FL 09-127	---	8.27 Aa	7.27 Bb	6.60 Ca
FL 10-47	---	7.00 Ae	6.70 Bc	5.50 Ce
'Strawberry Festival'	8.27 Ac	6.80 Be	6.50 Cd	6.10 Db
'Florida Radiance'	7.40 Ad	6.20 Bf	7.47 Aa	5.53 Ce
P-value (genotype)	<0.0001	<0.0001	<0.0001	<0.0001
P-value (harvest date)		<0.0001		
P-value (harvest date × genotype)		<0.0001		

[z]Mean separations as uppercase within rows by LSD test at $P \leq 0.05$.
[y]Mean separations as lowercase within columns by LSD test at $P \leq 0.05$.
[x]Least squares means not estimable resulting from missing samples due to low yield or unbalanced replication.

Table 3. Fructose content of strawberry commercial varieties and University of Florida advanced selections measured on four harvest dates during the 2011-12 strawberry season.

	Fructose (g·100 g^{-1})			
Genotype	Mid-January	Late January	Mid-February	Late February
Winterstar™ FL 05-107	3.18 A[z]b[y]	1.82 Cf	2.23 Bd	1.35 Df
FL 06-38	---[x]	3.72 Aa	2.97 Ba	2.81 Ca
FL 07-193	3.31 Aa	1.80 Bf	1.69 Ce	1.68 Ce
FL 09-127	---	3.00 Ab	2.76 Bb	2.51 Cb
FL 10-47	---	2.57 Ad	2.41 Bc	1.97 Cd
'Strawberry Festival'	2.77 Ac	2.70 Ac	2.19 Bd	2.26 Bc
'Florida Radiance'	2.62 Ad	1.94 Ce	2.35 Bc	---
P-value (genotype)	<0.0001	<0.0001	<0.0001	<0.0001
P-value (harvest date)		<0.0001		
P-value (harvest date × genotype)		<0.0001		

[z]Mean separations as uppercase within rows by LSD test at $P \leq 0.05$.
[y]Mean separations as lowercase within columns by LSD test at $P \leq 0.05$.
[x]Least squares means not estimable resulting from missing samples due to low yield or unbalanced replication.

Table 4. Glucose content of strawberry commercial varieties and University of Florida advanced selections measured on four harvest dates during the 2011–12 strawberry season.

	Glucose (g·100 g^{-1})			
Genotype	Mid-January	Late January	Mid-February	Late February
Winterstar™ FL 05-107	2.91 A[z]b[y]	1.25 Ce	1.97 Bc	1.28 Ce
FL 06-38	---[x]	2.73 Aa	2.01 Bc	1.82 Cc
FL 07-193	3.08 Aa	1.84 Cc	2.01 Bc	1.98 Bb
FL 09-127	---	2.80 Aa	2.46 Ba	2.30 Ca
FL 10-47	---	2.24 Ab	2.01 Bc	1.52 Cd
'Strawberry Festival'	3.07 Aa	1.89 Bc	1.97 Bc	1.53 Cd
'Florida Radiance'	2.63 Ab	1.42 Cd	2.14 Bb	---
P-value (genotype)	<0.0001	<0.0001	<0.0001	<0.0001
P-value (harvest date)		<0.0001		
P-value (harvest date × genotype)		<0.0001		

[z]Mean separations as uppercase within rows by LSD test at $P \leq 0.05$.
[y]Mean separations as lowercase within columns by LSD test at $P \leq 0.05$.
[x]Least squares means not estimable resulting from missing samples due to low yield or unbalanced replication.

38 fruit harvested in late-January was highest compared to other strawberry genotypes throughout the 2011–12 season. FL 07-193 and Winterstar™ FL 05-107 harvested in mid-January showed higher fructose contents (3.31 and 3.18 g·100 g^{-1}), respectively, compared to other genotypes.

The high temperatures measured during the late-February harvest most likely contributed to the reduction in the SSC observed for all genotypes (Table 2). According to the Florida Automated Weather Network (University of Florida/IFAS, 2012), in mid-January the average daily temperature on the day of harvest was 14 °C, whereas in late-February the daily average temperature was 23 °C (Table 5). Mackenzie and Chandler (2009) also reported

Table 5. Average daily temperature, minimum and maximum temperature measured during four harvest dates throughout 2011–12 strawberry season in Balm, FL.

	Temperature (°C)		
Harvest date	Avg daily	Minimum	Maximum
16 Jan. 2012	14	5	22
30 Jan. 2012	16	9	24
13 Feb. 2012	10	0	20
27 Feb. 2012	23	18	29

Table 6. Pearson correlation coefficients (*r*) for pairs of fruit chemical traits from a trial of University of Florida strawberry cultivars and advanced selections.

Variables	SSC	Total sugars	Glucose	Fructose
SSC	1.00[z]	0.72	0.76	0.60
Total sugars		1.00	0.93	0.94
Glucose			1.00	0.76
Fructose				1.00

[z]Values are different from 0 with a significance level $\alpha = 0.05$

a decline in SSC at the end of the strawberry growing season in Florida, when temperatures were higher. The temperature pattern throughout the season most likely influenced the decline or increase in SSC and TS concentrations observed as the season progresses. Winterstar™ FL 05-107 showed decreased TS content from mid-January to late-January. However, the decrease in temperature in mid-February may have contributed to an increase in TS content in Winterstar™ FL 05-107 fruit. In 'Strawberry Festival' SSC and TS slightly decreased from late-January to late-February harvests but a sharp decrease occurred in fruit harvested late January. SSC and TS were highly correlated with one another. In addition, high correlations among glucose and fructose with SSC and TS were found (Table 6). Sucrose was not detected in all genotypes; therefore data are not presented here. Glasziou and Gayler (1972) reported that in some plant tissue, sucrose is believed to be hydrolyzed by an invertase in the free space before uptake. The accumulation of glucose and fructose might occur more rapidly than sucrose in strawberry fruit tissue if sucrose is hydrolyzed before uptake (Forney and Breen, 1986). Many factors might have accelerated sucrose hydrolysis upon detachment of strawberries from the plant or due to delay in cooling the fruit during transport to the laboratory.

Genotypes seem to respond to field temperature differently. Selection FL 09-127 was the top genotype for TS content on both February harvests and second in January. This suggests that this genotype may have consistently good eating quality, which has been confirmed in taste panels (unpublished data). There are also appealing trends for other genotypes. For example, selection FL 06-38 was the highest or second highest genotype for TS content throughout the season, exhibiting a slight decrease of SSC on all dates where it was measured. The behavior of 'Florida Radiance' also is noticeable because TS content varied more across harvest dates than for others genotypes. Significant genotype × harvest date interaction for all sugar traits demonstrated that advanced selections must be compared over multiple harvest dates to determine the seasonal stability of sugars. Greater stability could result in new cultivars with more consistent flavor.

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