A Comparison of Physical and Chemical Attributes of Strawberry Cultivars and Advanced Breeding Selections from the University of Florida

KATRINA KELLY¹, CECILIA DO NASCIMENTO NUNES³*, and VANCE M. WHITAKER²

¹University of South Florida, Department of Cell Biology, Microbiology and Molecular Biology, Tampa, FL 33620
²Gulf Coast Research and Education Center, University of Florida, 14625 CR 672, Wimauma, FL 33815

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Postharvest performance is an important consideration when developing a new strawberry cultivar. The objectives of this study were to evaluate the quality of advanced strawberry selections and compare them to commercial cultivars. ‘Florida Radiance’ and ‘Sensation® Florida127’, and six advanced selections from the University of Florida breeding program were evaluated over seven harvests. Each cultivar and advanced selection was evaluated for appearance, weight loss, texture, soluble solids content (SSC), acidity, total phenolics (TPC), and ascorbic acid (AA) on the day of harvest and after a 7-day storage period at 2 °C. On average, ‘Florida Radiance’, FL 10-166 and FL 12-5-103 scored higher for appearance at harvest; however, FL 12-5-103 had the best appearance after storage and the least amount of weight loss. FL 12-26-49 was the firmest strawberry at harvest and remained the firmest after the 7-day storage period. FL 12-70-55 had the lowest SCC after storage despite having the highest initial SSC. The highest titratable acidity was measured in FL 12-55-220, FL 12-70-55, and FL 12-121-5 on the day of harvest. The highest TPC was measured in FL 10-166, which also had the highest TPC at the end of storage. Compared to the other strawberry genotypes, FL 12-55-220 maintained the highest levels of AA throughout storage. Results from this study showed that there is a significant interaction between genotype and specific quality attributes. The results also provide information valuable to the selection process by identifying new genotypes with improved compositional attributes combined with suitable quality characteristics after cold storage.

Florida is the second largest producer of strawberries in the United States after California. It is the main supplier to the Eastern and Midwestern regions of the United States during the winter months (Del Pozo-Insfran, 2006). Strawberries are also second only to citrus as the largest fruit crop grown in Florida, generating nearly $300 million dollars in 2015 for the Florida industry (USDA National Agricultural Statistics Service, 2015). The Florida strawberry industry not only needs to compete with production from other states, but also with imported strawberries from other countries, namely Mexico. According to the Food and Agricultural Organization of the United Nations (FAO), Mexico produced 379,464 tons of strawberries during 2013, more than a twofold increase from the 141,130 tons produced in 2000 (FAO, 2015). With most of Mexico’s exports coming to the US, it is necessary for the Florida strawberry industry to remain competitive by developing cultivars that are well adapted to the Florida climate while maintaining their freshness through the supply chain. A strawberry which is exceptional at harvest does not guarantee one with superior quality after handling and storage. Strawberries are a highly perishable fruit, and if they senesce too quickly, they are likely be unmarketable by the time they reach the market. There are many factors that can affect how a strawberry variety will behave during storage including genetics, pre-harvest climatic conditions, and postharvest conditions (Prange 1997). Pre-harvest climatic conditions can be hard to control as the climate varies from year to year and can sometimes be unpredictable. Managing postharvest conditions can also be difficult since it is not guaranteed that the fruit will be stored at the optimum temperature and humidity throughout the supply chain. Cultivar selection is probably the most important way of managing postharvest quality since nearly all the postharvest quality factors are controlled by genetics (Prange 1997). Developing a Florida strawberry with exceptional postharvest shelf life will provide a better quality strawberry to the consumer.

In this study, we evaluated two standard commercial cultivars ‘FloridaRadiance’ and ‘Sensation® Florida127’ (hereafter referred to as ‘Florida127’) and six advanced breeding selections (hereafter referred to as ‘genotypes’) from the University of Florida strawberry breeding program. We compared six advanced breeding selections against ‘Florida Radiance’ and ‘Florida127’ to determine which genotypes performed as well as, or better than, the standard commercial cultivars. The data from this study will aid in the selection of the next strawberry cultivar to be released to commercial growers by providing insight into how each advanced breeding selection behaves during postharvest storage.

*Corresponding author: mariacecilia@usf.edu
Materials and Methods

**Plant Material and Experimental Setup.** Strawberries were grown under standard commercial practices at the University of Florida, Gulf Coast Research and Education Center located in Balm, FL during the 2014-2015 production season. Bare-root runner plants were planted on two-row raised beds covered with black polyethylene mulch. A mixture of talcine (65%) and chloropicrin (35%) was used to fumigate beds before planting in October of each year. Strawberry genotypes were selected based on availability and potential commercial value: ‘Florida Radiance’ and ‘Florida127’ were commercially grown in Florida, while FL 10-166, FL 12-5-103, FL 12-26-49, FL 12-55-220, FL 12-70-55, and FL 12-121-5 were new strawberry breeding selections. Four replicate plots (10 plants per plot) of each genotype were planted in a randomized complete block design in mid-October 2015. Fruit were hand-harvested when three-quarters red to fully-red in color (standard commercial ripeness). Samples of at least 20 fruit per genotype were collected for analysis on the mornings of 8 and 15 Dec. 2014, and on 12 and 26 Jan., 2 and 23 Feb., and 2 Mar. 2015. After sorting, 10 to 15 fruit per genotype were selected and placed inside a plastic clamshell (453g; Wasserman Bag Co., Inc., New York). The clamshells containing the fruit were stored in a temperature and humidity-controlled chamber set at 1.5 °C and 85% RH (Forma Environmental Chambers Model 3940 Series, Thermo Electron Corporation, OH) and quality was evaluated daily during a 7-d storage period. These conditions simulated the lowest temperature and highest RH measured during strawberry handling (Nunes et al., 2009; Lai et al., 2011; Pelletier et al., 2011).

**Sensory Quality.** Sensory quality evaluation of ‘Florida Radiance’, ‘Florida127’, and the six advanced breeding selections was performed every day during a 7-d storage period, always by the same trained persons. Color, shriveling, and decay severity were determined subjectively using a 1–5 visual rating as described by Nunes (2015). For ease of interpretation, individual ratings for color, shriveling and decay were averaged and reported as appearance. A score of 3 was considered to be the limit of acceptability for sale.

**Texture Analysis.** The firmness of each strawberry was measured using a TA.XT Plus Texture Analyzer (Texture Technologies Corp., New York) as described by Whitaker et al. (2012). The force required to compress the fruit by 3 mm was recorded in kgf.

**Weight Loss and Dry Weight.** Weight loss of three replicated samples of 10 to 15 strawberries each was calculated from the initial weight of the fruit and every day during a 7-day storage period. Concentrations of chemical constituents were expressed in terms of dry weight to show the differences between cultivars that might be obscured by differences in water content. The following formula was used for water loss corrections: [chemical components (fresh weight) x 100 g / strawberry dry weight + weight loss during storage (g)]. Strawberry dry weight was determined by drying three weighed aliquots of homogenized strawberry tissue at 80 °C until weight stabilized.

**Soluble Solids Content.** Fifteen individual fruit per treatment were homogenized in a laboratory blender at high speed for 2 min. The resulting puree was immediately frozen and kept at −30 °C until used. SSC was determined according to Nunes et al. (1995).

**Total Phenolic Content.** Total soluble phenolic compounds were measured using the Folin-Ciocalteau reagent as described by Nunes et al. (2005).

**Total Ascorbic Acid Content.** Total ascorbic acid was quantified by mixing 2 g of homogenate with 20 mL metaphosphoric acid mixture (6% HPO4 containing 2 N Acetic acid). Samples were then filtered (0.22 µm) before HPLC analysis. The ascorbic acid analysis was conducted using a Hitachi LaChromUltra UHPLC system with a diode array detector and a LaChromUltra C18 2µm column (2 x 50 mm) (Hitachi, Ltd., Tokyo, Japan). The analysis was performed under isocratic mode at a flow rate of 0.5 mL/min with a detection of 254 nm. Sample injection volume was 5 µL, each with duplicate HPLC injections. Mobile phase was buffered potassium phosphate monobasic (KH2PO4, 0.5%, w/v) at pH 2.5 with metaphosphoric acid (HPO4, 0.1%, w/v). The retention time of the ascorbic acid peak was 2.5 min. After comparison of retention time with the ascorbic acid standard, the peak was identified. The amount of total ascorbic acid content in strawberry was quantified using calibration curves obtained from different concentrations (10 µg·mL−1, 20 µg·mL−1, 30 µg·mL−1, 50 µg·mL−1, 100 µg·mL−1, 150 µg·mL−1, 200 µg·mL−1 and 300 µg·mL−1) of ascorbic acid standards.

**Statistical Analysis.** The Statistical Analysis System computer package (SAS Institute, Inc., 2004) was used for the analysis of the data from these experiments. The data was analyzed using two-way analysis of variance (ANOVA) with harvest, cultivar, and storage time as main effects. Although there was a significant difference between harvests for most of the quality attributes measured, the trends were similar. Therefore, for ease of interpretation, data from the seven harvests were combined. Significant differences among cultivars were detected using the least significant difference (LSD) at the 5% level of significance.

Results and Discussion

**Appearance.** Appearance is the first quality attribute considered by the consumer and any strawberry that appears overripe, shriveled, or shows signs of decay will be rejected (Shin et al., 2008). Therefore, it is important to evaluate fruit appearance not only at harvest but during a minimum of a 7-day storage period under commercial conditions. In this study, there was a decrease in the appearance of the fruit over the 7-day storage period, regardless of the cultivar or genotype. However, the quality of none of the cultivars or genotypes fell below the lowest acceptable rating of 3 after storage (Table 1). The genotype FL 12-5-103 had the highest appearance rating at the end of storage with an average rating of 3.70 while ‘Florida Radiance’ had the lowest rating at 3.28. Both of these ratings fall within the acceptable, yet ‘Florida Radiance’ was very close to falling below the acceptable rating of 3.0. This means that it was barely acceptable most of the time and possibly unacceptable at sometimes because this rating was an average for all seven harvests. The genotype FL 12-5-103 was acceptable more often than ‘Florida Radiance’ since its average rating was closer to 4.0. Consequently, it is less likely that it will fall below a rating of 3.0 throughout the season. FL 12-5-103 was also the only genotype which performed better than both of the standard cultivars. It was the only one which had a higher rating than ‘Florida127’ at the end of the storage period. Overall, all genotypes performed better than ‘Florida Radiance’ maintaining their appearance throughout storage.

**Weight Loss.** Another attribute to consider when evaluating strawberry shelf life is weight loss during storage. A strawberry loses weight in the form of moisture, which can deplete the fruit of nutrients and make it appear shriveled. The changes in color and texture which occur when a strawberry loses moisture can make it appear unacceptable to the consumer (Nunes and Emond, 2007). Of all the strawberry cultivars and genotypes studied, FL 12-5-103 had the lowest percent weight loss (7.5%) over the seven...
harvests (Fig. 1). This correlates to its high appearance ratings (Table 1). FL 12-5-103 was also the only genotype which lost less weight than either of the standard cultivars, ‘Florida Radiance’ or ‘Florida127’, which both lost an average of 9.3% and 9.7% respectively. High weight loss is not always a predictor of low appearance ratings. This can be seen with genotype FL 10-166 which lost an average of 10.4% of its weight, the third highest weight loss of all the cultivars and genotypes studied, yet it had the third highest average appearance rating at day 7 (Table 1).

**Texture**. Texture is another very important quality attribute to take into consideration because it is highly correlated with consumer satisfaction. Consumers have a predefined notion of how soft or crunchy a strawberry should be, and an overly crunchy strawberry could be perceived as under ripe while a soft strawberry could be considered overripe. Therefore, a strawberry should have the right balance of softness to crunchiness to appeal to the consumer (Schwieterman et al., 2014). In this study, the genotype FL 12-26-49 had the firmest texture at harvest whereas FL 12-70-55 was the softest among all genotypes (Table 2). In addition, firmness of FL 12-26-49 was significantly higher than ‘Florida Radiance’ or ‘Florida127’. The genotype FL 12-26-49 might be an example of a strawberry which is too firm at harvest and could be perceived as under ripe. However, at the end of storage, its texture was very similar to that of ‘Florida Radiance’ at harvest. This could be beneficial when strawberries need to be transported long distances to market. It might initially be too firm but by the time it reaches the consumer, the fruit would still have an acceptable texture. On the other hand, genotype FL 12-70-55 was the softest strawberry both at harvest and after storage. A strawberry that is too soft is more likely to be damaged during transport. Bruising leads to faster degradation of the fruit and increases the chances of spoilage by pathogens. The softer texture and high weight loss of genotype FL 12-70-55 probably contributed to its low appearance ratings after storage (Table 1).

**Soluble Solids Content**. The measurement of soluble solids content (SSC) constitutes a good way to estimate the amount of sugar present in a strawberry where a higher SSC is usually correlated with a sweeter strawberry (Jouquand et al., 2008). At harvest, genotype FL 12-70-55 had the highest SSC. However during storage SSC significantly declined, and by day 7 this genotype had the lowest SSC compared to the other cultivars or genotypes (Table 3). The standard commercial cultivars, by comparison, had the smallest decrease in SSC during storage. The genotype FL 12-70-55 seemed to be a superior strawberry regarding SSC at harvest, but SSC declined below all the other cultivars and genotypes during storage. ‘Florida Radiance’ had the lowest SSC at harvest but after storage, it was not significantly different from FL 12-70-55. Nearly all of the genotypes studied performed better

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![Fig. 1. Weight loss of strawberry genotypes from seven different harvests](image)

Table 1. Average appearance ratings of strawberry commercial cultivars and genotypes from seven different harvests on the day of harvest (day 0) and after 7 d at 1.5 °C.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Appearance¹</th>
<th></th>
<th>Day 7</th>
<th>Decrease (%)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Day 0</td>
<td>Day 7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>‘Florida Radiance’</td>
<td>4.97 ab</td>
<td>3.28 e</td>
<td>34.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>‘Florida127’</td>
<td>4.96 ab</td>
<td>3.52 bc</td>
<td>29.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FL 10-166</td>
<td>4.97 ab</td>
<td>3.50 c</td>
<td>29.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FL 12-5-103</td>
<td>4.98 a</td>
<td>3.70 a</td>
<td>25.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FL 12-26-49</td>
<td>4.86 c</td>
<td>3.50 c</td>
<td>28.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FL 12-55-220</td>
<td>4.93 b</td>
<td>3.42 cd</td>
<td>30.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FL 12-70-55</td>
<td>4.95 ab</td>
<td>3.31 de</td>
<td>33.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FL 12-121-5</td>
<td>4.94 ab</td>
<td>3.43 dc</td>
<td>30.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹Rating scores: 1 = very poor; 3 = acceptable; 5 = excellent. A score of 3 was considered to be the limit of acceptability for sale.

²Means within a column followed by the same letter are not significantly different, P > 0.05.

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Table 2. Average texture of strawberry commercial cultivars and genotypes from seven different harvests on the day of harvest (day 0) and after 7 d at 1.5 °C.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Day 0</th>
<th>Day 7</th>
<th>Decrease (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Florida Radiance’</td>
<td>0.54 c</td>
<td>0.47 bcde</td>
<td>13.0</td>
</tr>
<tr>
<td>‘Florida127’</td>
<td>0.62 c</td>
<td>0.47 bcd</td>
<td>24.2</td>
</tr>
<tr>
<td>FL 10-166</td>
<td>0.68 b</td>
<td>0.49 b</td>
<td>27.9</td>
</tr>
<tr>
<td>FL 12-5-103</td>
<td>0.55 de</td>
<td>0.44 cde</td>
<td>20.0</td>
</tr>
<tr>
<td>FL 12-26-49</td>
<td>0.92 a</td>
<td>0.55 a</td>
<td>40.2</td>
</tr>
<tr>
<td>FL 12-55-220</td>
<td>0.59 cd</td>
<td>0.44 de</td>
<td>25.4</td>
</tr>
<tr>
<td>FL 12-70-55</td>
<td>0.45 f</td>
<td>0.37 f</td>
<td>17.8</td>
</tr>
<tr>
<td>FL 12-121-5</td>
<td>0.60 cd</td>
<td>0.46 de</td>
<td>23.3</td>
</tr>
</tbody>
</table>

²Means within a column followed by the same letter are not significantly different, P > 0.05.

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Table 3. Average soluble solids content (SSC) of strawberry commercial cultivars and genotypes from seven different harvests on the day of harvest (day 0) and after 7 d at 1.5 °C.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Day 0</th>
<th>Day 7</th>
<th>Decrease (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Florida Radiance’</td>
<td>83.37 gr</td>
<td>43.99 de</td>
<td>47.2</td>
</tr>
<tr>
<td>‘Florida127’</td>
<td>92.15 bcd</td>
<td>49.28 a</td>
<td>46.5</td>
</tr>
<tr>
<td>FL 10-166</td>
<td>92.31 abcd</td>
<td>45.94 bcd</td>
<td>50.2</td>
</tr>
<tr>
<td>FL 12-5-103</td>
<td>91.67 bcd</td>
<td>47.70 ab</td>
<td>48.0</td>
</tr>
<tr>
<td>FL 12-26-49</td>
<td>93.05 abc</td>
<td>46.27 bc</td>
<td>50.3</td>
</tr>
<tr>
<td>FL 12-55-220</td>
<td>91.05 cdef</td>
<td>44.57 cde</td>
<td>51.0</td>
</tr>
<tr>
<td>FL 12-70-55</td>
<td>93.35 a</td>
<td>42.65 e</td>
<td>54.3</td>
</tr>
<tr>
<td>FL 12-121-5</td>
<td>88.78 f</td>
<td>46.07 bc</td>
<td>48.1</td>
</tr>
</tbody>
</table>

²Means within a column followed by the same letter are not significantly different, P > 0.05.

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than ‘Florida Radiance’ and the most recent release ‘Florida 127’ showed the lowest decrease in SSC after storage.

**Total Phenolic Contents and Ascorbic Acid.** Polyphenolic compounds and ascorbic acid are important bioactive molecules found in strawberries. Not only do these compounds protect the strawberry plant from disease, but they also serve as potent antioxidants when eaten by consumers (Kähkönen et al., 2001). Ascorbic acid, also known as vitamin C, is an essential component of the human diet. Ascorbic acid provides acidity to the strawberry whereas phenolic acids impart bitterness if found in high concentrations. Polyphenols also comprise a group of compounds called anthocyanins which give the strawberry its attractive red coloration (Aaby et al., 2012). At harvest, genotype FL 10-166 contained the highest concentration of total phenolic compounds and it still had the highest concentration of all varieties after storage (Table 4). This was significantly higher than both of the two standard cultivars. ‘Florida 127’ had the lowest amount of total phenolics at harvest which correlated to its light red color (data not shown). The cultivar ‘Florida 127’ is also a sweet strawberry which may be due to a combination of its high SSC and a low level of total phenolic compounds and a lack of bitterness that comes with a high phenolic content.

Ascorbic acid is a very labile compound which oxidizes very quickly under adverse conditions; therefore, it is often considered a good indicator of freshness in harvested strawberries (Nunes et al., 1995). In this study, FL 12-5-103 had the lowest decrease in ascorbic acid over the 7-day storage period compared to the other genotypes (Table 5). It also had the highest amount of ascorbic acid after storage. It is interesting to note that the two genotypes FL 12-121-5 and FL 12-70-55 and the commercial standard cultivar ‘Florida Radiance’ had the lowest amount of ascorbic acid after storage and were also those that had the lowest appearance ratings (Table 1).

**Conclusions**

Overall, the rate of quality degradation varied widely between all genotypes and cultivars used in this study. The cultivars, ‘Florida Radiance’ and ‘Florida 127’, showed the most stability during storage as they largely had the lowest percentage of decrease in each quality attribute with a few exceptions. Several genotypes were comparable to, or out-performed, the standard commercial cultivars, which indicates that progress is being made to improve Florida strawberry cultivars. This study also showed that high quality at the end of storage was not always guaranteed by the most robust genotypes or cultivars at harvest reinforcing the importance of postharvest quality studies when considering the next commercial strawberry.

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