Historical Trends in Strawberry Fruit Quality Revealed by a Trial of University of Florida Cultivars and Advanced Selections

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Abstract. The University of Florida strawberry (Fragaria xananassa Duch. ex Rosier) breeding program has maintained a continuous breeding effort since 1968 to develop cultivars that are highly adapted to winter production in west-central Florida. To gain insight into breeding progress over time, two advanced selections (UF1 and UF2) and 10 released cultivars, from Florida Belle (1975) to Florida Radiance (2008), were compared for various fruit quality traits in a two-location field study during the 2009–2010 season. Fruit size varied dramatically from 30.8 g for ‘Elyana’ to 16.2 g for ‘Dover’ at Balm, FL, and from 28.3 g for UF2 to 16.6 g for ‘Dover’ at Dover, FL. A linear regression of fruit size on year of release revealed an average gain of 2.6 g per year since 1975 for the cultivars and selections tested ($R^2 = 0.44$). A similar analysis revealed a reduction over time in the proportion of cull fruit ($R^2 = 0.30$). Gains were apparent for the redness of the internal flesh, from a colorimeter $a^*$ value of 16.1 for ‘Florida Belle’ (1975) to 34.7 for ‘Carmine’ (2002) but were not sustained for later releases and selections. Although there were significant differences among genotypes for all chemical traits affecting flavor, there were no discernable patterns over time. There were wide month-to-month variations in individual sugars and organic acids, except for citric acid, which was stable across months and locations. The ratio of soluble solids content to titratable acidity ranged widely among genotypes, from a high of 15.7 for ‘Florida Belle’ in February at Dover, FL, to a low of 6.4 for ‘Winter Dawn’ in January at Balm, FL. The observed variability and trends in fruit quality traits will help guide future genetic studies and inform decisions about future breeding priorities and selection procedures.

The University of Florida (UF) strawberry (Fragaria xananassa) breeding program develops cultivars adapted for winter fruit production in west-central Florida. This region is the second leading production area in the United States behind coastal California with a harvested area of $\approx$9000 acres and a crop valued at $\$313$ million during the 2010–2011 season (http://www.nass.gov). A continuous breeding effort has existed since 1968. The University of Florida has released 10 cultivars during this period. Dr. Charles Howard released ‘Florida Belle’ (1975) and ‘Dover’ (1979). Dr. Craig K. Chandler released ‘Sweet Charlie’ (1992) (Chandler et al., 1997a), ‘Rosa Linda’ (1996) (Chandler et al., 1997b), ‘Earlbrite’ (2000) (Chandler et al., 2000a), ‘Strawberry Festival’ (2000) (Chandler et al., 2000b), ‘Carmine’ (2002) (Chandler et al., 2004), ‘Winter Dawn’ (2005), ‘Florida Radiance’ (2008) (Chandler et al., 2009b), and ‘Florida Elyana’ (2008) (Chandler et al., 2009a). In 2009–2010, the most-used cultivars were ‘Strawberry Festival’ and ‘Florida Radiance’, which occupied $\approx$60% and 10% of planted acreage, respectively. The UF strawberry breeding program has sought to improve fruit quality attributes over time through phenotypic recurrent selection. Some traits such as external color, fruit size, and fruit uniformity are regularly selected based on field observations. New cultivar releases have been compared with one or more established cultivars to document improvements in yield, fruit size, and disease resistance (Chandler et al., 2009a, 2009b). Other traits influencing flavor perception such as soluble solids content (SSC), titratable acidity (TA), individual sugars and acids, and volatile compounds have been selected only indirectly by tasting fruit in the field. A recent evaluation of a limited number of Florida varieties and advanced selections revealed variation in eating quality through sensory evaluation as well as variation in SSC, TA, and volatile components (Jouquand et al., 2008).

Retrospective analyses have been conducted for a number of crops to evaluate genetic progress over time for important traits. For example, a field study of cotton cultivars released between 1918 and 1982 showed steady linear increases for some traits, whereas other traits showed improvement early in the breeding program but experienced a plateau in later generations. Still other traits were variable among cultivars but exhibited no discernable trend over time (Bayles et al., 2005). Shaw and Larson (2008) compared two sets of cultivars released from the University of California–Davis strawberry breeding program from 1945–1966 and from 1993–2004 showing significant progress for fruit size, yield, and appearance. Approximate selection responses for the different traits ranged from 1% to 3% per year.

The purpose of this study was to evaluate relevant fruit quality attributes of UF strawberry cultivars and two advanced selections. Examination of fruit quality traits and their temporal trends should help inform future strategies for genetic improvement.

Materials and Methods

Plant materials and cultural practices

The 10 cultivars released since 1968 and UF1 and UF2, two selections being considered for release at the time of this study, were evaluated during the 2009–2010 season. The experiment was conducted across two locations. The trial grounds of the Florida Strawberry Growers Association at Dover, FL, was the location of the UF breeding program from 1968 to 2004, whereas the Gulf Coast Research and Education Center (GCREC) at Balm, FL, has served as the base of the breeding program from 2005 to the present.

Each trial site was prepared and maintained according to current commercial practices for annual strawberry plasticulture in Florida. Pre-plant fumigant consisted of a 50:50 mixture of methyl bromide and chloropicrin. Strawberry transplants were propagated in plug trays at the GCREC greenhouse facilities from runners collected at the GCREC and were typical for trials of advanced selections. Four replicate plots (10 plants/plot) of each genotype were planted in a randomized complete block design at Dover and Balm on 14 and 15 Oct., respectively. Two of intermittent overhead irrigation were applied for plant establishment, after which water and fertilizer were applied exclusively through the drip tape.

Fruit quality traits

Physical. Fully-ripe fruit were harvested twice weekly from the beginning of Dec. 2009 to the end of Mar. 2010 and graded in the laboratory at the GCREC. Fruit that were commercially unmarketable as a result of misshapenness, small size (less than 10 g), disease, and/or surface blemishes were recorded as culls and removed, and further analyses were performed on marketable fruit only. Fruit size was calculated as the total weight in grams divided...
by the total number of marketable fruit for the entire season. On 10 Mar. 2010, internal and external color were evaluated using a handheld colorimeter (Chroma Meter CR-400; Minolta, Ramsey, NJ) with a 1-cm aperture using the variables a* (green to red vector) and L* (black to white vector). One representative berry per replication was chosen for color analysis. External color was measured by taking two colorimeter readings on opposite sides of the fruit halfway between the calyx and tip. Internal color was measured by slicing the berry longitudinally and taking one reading per half (two per fruit) according to Shaw (1991).

Gloss, skin toughness, and uniformity were measured on 10 Mar. and firmness was measured on 10 Mar. 2010 and 2 Apr. on a subjective 1 to 5 scale with half-point increments. Ratings were conducted using a minimum of five berries per replication and were conducted by the same individual in all cases. Gloss was visually estimated under indoor fluorescent lighting (1 = dull, no gloss; 5 = highly reflective). Skin toughness was estimated by grasping the fruit between the thumb and forefinger (1 = minimal resistance to force; 5 = non-yielding to force). Uniformity was rated on the same fruit (1 = non-uniform surface within and among berries; 5 = uniform surface and shape within and among berries). Firmness was rated by applying pressure to the berry using the thumb and forefinger (1 = minimal resistance to force; 5 = non-yielding to force).

Chemical. Fruit from one harvest in January, February, and March were transported to force; 5 = non-yielding to force). To evaluate chemical traits with repeated observations over 3 months, correlations among measurements made on the same experimental unit were modeled using a first-order autoregressive covariance structure. The full model included genotype, location, block (nested within locations), and the genotype × location interaction as fixed effects. When the genotype × location interaction was significant (F-test, α = 0.05), the variables were analyzed separately by location; otherwise, the interaction was dropped from the model and the data analyzed for Balm and Dover collectively. For the subjective measures of firmness, gloss, skin toughness, and uniformity (1 to 5 scales), residuals were examined and determined to be about normal; no further improvements could be gained through standard transformations.

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The cultivars Festival (2000), Earlibrite (2000), and Carmine (2002) had higher a* values of 27.0, 28.4, and 34.7, respectively, indicating more intense color. However, these increases were not sustained in later cultivars and selections but rather decreased (Table 1). Selection for internal color became secondary to selection for earliness, fruit size, firmness, and flavor. Also, negative genetic correlations between internal flesh color and other traits may be present in the breeding program and should be examined in future studies. Shaw (1991) reported weak and/or insignificant genetic correlations between internal and external color measures in strawberries, indicating that internal and external redness are conditioned by different genes. Therefore, improving internal redness while avoiding external flesh that is overly dark should be possible.

Fig. 1. Percentage of cull fruit during the 2009–2010 season from a trial of University of Florida strawberry cultivars and advanced selections (shown by order of cultivar release date) conducted at two locations. Bars represent SEs.
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varied from 0.56% for UF1 to 1.05% for

Future varieties, such as ‘Elyana’ and ‘Florida Belle’,

were highly correlated with one another

published for strawberry in other studies;

panel ratings with high ratios associated with

increased perception of sweetness (Joquand

et al., 2008), which is consistent with the results

of other studies on strawberry flavor (Pelayo-

Zaldívar et al., 2005; Wozniak et al., 1997).

Because we have shown significant genetic

variation in UF germplasm for SSC, TA, and

SSC/TA and because these have been associ-

ated with taste preference, it should be possible
to breed for improved flavor by targeting optimal

values of these traits in the breeding program.

Month-to-month variation in individual

sugars and acids largely mirrored that of

SSC and TA (Table 3). Citric acid, however,

was very stable across both months and

environments, because genotype × month

and genotype × location interactions were

not significant (P > 0.05). Citric acid content

varied from 0.56% for UF1 to 1.05% for

‘Dover’. On the other hand, the malic

acid content of the cultivars and selections was

influenced by month and location. In all

environments and months, ‘Carminé’ had the

highest malic acid content with a maximum

of 0.83% in January at Balm. By

contrast, ‘Dover’ has the highest citric acid

content (1.05%) but ranged in malic acid

content from 0.10% to 0.20% across months

and locations. On occasion, ‘Carminé’ has

been noted as having an astringent mouth

feel, which could be from high malic acid,

a combination of high malic and citric acids,
or other phenolic compounds in the fruit.

Although phenolic compounds, specifically

tannins, are known to induce the feeling of

astrignency, studies have shown that malic

acid in water can induce stronger intensity

responses for astringency than for sourness

(Straub, 1989), and a malic acid/citric acid

mix can also induce astringency (Rubio and

McDaniel, 1992). The cultivar Winter Dawn

had the second highest malic acid content in

four of six cases and has also been noted as

having a sour and astringent taste in sensory

panels (Plotto et al., 2010).

Fructose and glucose contents were highly

influenced by month. Nevertheless, there was

a significant impact of genotype on sugar

contents (Table 3). Elyana was the cultivar

with the highest fructose and glucose content

in all cases; fructose ranged from 3.24%

in March at Balm to 6.29% in February at

Dover. Sucrose contents were measured but

the data fell outside of the range of values

published for strawberry in other studies;

therefore, the data were regarded as suspect

until further evaluations and are not pre-

sented here. Glucose and fructose contents

were highly correlated with one another

(r = 0.92, P < 0.0001) and were also highly

correlated with SSC (r = 0.87, P < 0.0001 and

r = 0.76, P < 0.0001, respectively). These

correlations confirm that SSC serves as a re-

liable approximation of glucose and fructose

content for UF germplasm. Shaw (1988)

reported that total sugars accounted for an

average of 66% of SSC, and other studies have

reported correlations between total sugars and

SSC ranging from r = 0.82 to r = 0.91 (Kallio

et al., 2000; Pelayo-Zaldívar et al., 2005)

Conclusions

Genotype explained a significant portion of

variation in all traits measured in this

study. For some traits such as fruit size and
cull rate, significant gains from recurrent
selection are apparent in the breeding pro-
gram. These remain very important traits for

industry acceptance, and selection pressure

for these traits must be maintained. Internal

redness is an example of a trait for which

progress was observed early in the breeding

program but gains were not sustained. This
trend may have resulted from a lack of in-
tentional selection for this trait compared with

other important traits. Attention to this trait

should be renewed, and genetic relationships

between internal color and other important

traits should be examined in future studies.

For chemical traits that affect flavor, no

obvious patterns were discernable over time.

These results may be reflective of various

factors, including differences in the herita-
bility of these traits, environmental variation,

the feasibility of selection, and breeding

priorities. Although fruit size is readily se-
lected in the field, sugars and organic acids

are selected only indirectly by tasting a small

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Table 3. Least square means and mean separations for individual sugars and acids of University of Florida strawberry cultivars and advanced selections sampled in January, February, and March. a

<table>
<thead>
<tr>
<th>Cultivar/selection</th>
<th>Yr of release</th>
<th>January/February/March</th>
<th>Malic acid (%)</th>
<th>Citric acid (%)</th>
<th>Fructose (%)</th>
<th>Glucose (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Balm and Dover</td>
<td>Balm</td>
<td>Balm</td>
<td></td>
<td>Balm</td>
</tr>
<tr>
<td>UF2</td>
<td>2012</td>
<td>0.78 de</td>
<td>0.30 d</td>
<td>0.27 b</td>
<td>0.17 cde</td>
<td>3.41 bc</td>
</tr>
<tr>
<td>UF1</td>
<td>2011</td>
<td>0.56 f</td>
<td>0.34 d</td>
<td>0.17 de</td>
<td>0.19 cd</td>
<td>3.40 bc</td>
</tr>
<tr>
<td>Radiance</td>
<td>2008</td>
<td>0.78 de</td>
<td>0.31 de</td>
<td>0.11 ef</td>
<td>0.21 c</td>
<td>2.42 de</td>
</tr>
<tr>
<td>Elyana</td>
<td>2008</td>
<td>0.79 de</td>
<td>— —</td>
<td>0.14 def</td>
<td>0.13 ef</td>
<td>— —</td>
</tr>
<tr>
<td>Winter Dawn</td>
<td>2005</td>
<td>0.95 b</td>
<td>0.60 b</td>
<td>0.16 de</td>
<td>0.28 b</td>
<td>2.26 e</td>
</tr>
<tr>
<td>Carime</td>
<td>2002</td>
<td>0.93 b</td>
<td>0.83 a</td>
<td>0.37 a</td>
<td>3.03 bcd</td>
<td>2.86 e</td>
</tr>
<tr>
<td>Festival</td>
<td>2000</td>
<td>0.84 cd</td>
<td>0.49 c</td>
<td>0.26 bc</td>
<td>0.20 c</td>
<td>2.84 cde</td>
</tr>
<tr>
<td>Earlibrite</td>
<td>2000</td>
<td>0.91 bc</td>
<td>0.22 ef</td>
<td>0.11 ef</td>
<td>0.09 f</td>
<td>3.69 ab</td>
</tr>
<tr>
<td>Rosa Linda</td>
<td>1996</td>
<td>0.97 ab</td>
<td>0.54 bc</td>
<td>0.20 cd</td>
<td>— —</td>
<td>3.56 abc</td>
</tr>
<tr>
<td>Sweet Charlie</td>
<td>1992</td>
<td>0.75 de</td>
<td>0.16 f</td>
<td>0.12 ef</td>
<td>0.17 cde</td>
<td>4.36 ab</td>
</tr>
<tr>
<td>Dover</td>
<td>1979</td>
<td>1.05 a</td>
<td>0.20 f</td>
<td>0.13 def</td>
<td>0.14 def</td>
<td>2.85 cde</td>
</tr>
<tr>
<td>Florida Belle</td>
<td>1975</td>
<td>0.72 e</td>
<td>0.21 f</td>
<td>0.09 f</td>
<td>0.11 f</td>
<td>3.72 ab</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UF2</td>
<td>2012</td>
<td>0.21 ab</td>
<td>0.22 a</td>
<td>0.17 bcd</td>
<td>3.50 abc</td>
<td>4.26 cde</td>
</tr>
<tr>
<td>UF1</td>
<td>2011</td>
<td>0.38 a</td>
<td>0.14 bc</td>
<td>0.16 bcd</td>
<td>3.61 ab</td>
<td>3.52 de</td>
</tr>
<tr>
<td>Radiance</td>
<td>2008</td>
<td>0.26 ab</td>
<td>0.09 de</td>
<td>0.15 cd</td>
<td>2.53 cde</td>
<td>2.67 f</td>
</tr>
<tr>
<td>Elyana</td>
<td>2008</td>
<td>0.24 ab</td>
<td>0.19 ab</td>
<td>0.13 cd</td>
<td>3.55 abc</td>
<td>3.62 a</td>
</tr>
<tr>
<td>Winter Dawn</td>
<td>2005</td>
<td>0.26 ab</td>
<td>0.14 bc</td>
<td>0.22 b</td>
<td>1.83 e</td>
<td>2.52 f</td>
</tr>
<tr>
<td>Carime</td>
<td>2002</td>
<td>0.33 a</td>
<td>0.22 a</td>
<td>0.28 a</td>
<td>2.74 bede</td>
<td>3.09 ef</td>
</tr>
<tr>
<td>Festival</td>
<td>2000</td>
<td>0.21 ab</td>
<td>0.20 ab</td>
<td>0.19 bc</td>
<td>2.47 de</td>
<td>4.80 abc</td>
</tr>
<tr>
<td>Earlibrite</td>
<td>2000</td>
<td>0.10 ab</td>
<td>0.07 de</td>
<td>0.09 de</td>
<td>3.13 abcd</td>
<td>5.29 ab</td>
</tr>
<tr>
<td>Rosa Linda</td>
<td>1996</td>
<td>— —</td>
<td>— —</td>
<td>— —</td>
<td>— —</td>
<td>— —</td>
</tr>
<tr>
<td>Sweet Charlie</td>
<td>1992</td>
<td>0.17 ab</td>
<td>0.12 bcd</td>
<td>0.12 cde</td>
<td>4.30 a</td>
<td>2.88 ef</td>
</tr>
<tr>
<td>Dover</td>
<td>1979</td>
<td>0.14 ab</td>
<td>0.10 cde</td>
<td>0.16 cd</td>
<td>2.66 bede</td>
<td>2.35 f</td>
</tr>
<tr>
<td>Florida Belle</td>
<td>1975</td>
<td>0.12 ab</td>
<td>0.05 e</td>
<td>0.08 e</td>
<td>3.12 abcd</td>
<td>3.65 cde</td>
</tr>
</tbody>
</table>

R²adj 0.03 0.32 0.16 0.10 0.05 0.03 0.03 >0.01 0.03 0.04

a For traits with non-significant genotype × environment interactions (P > 0.05), data are combined across sites.

b Projected year of release.

*Means within a column with the same letter are not significantly different using least significant difference at P < 0.05.

*Least squares means not estimable as a result of insufficient or unbalanced replication.

**R² statistics from regressions of traits on year of release.

continue to be performed to more firmly establish the optimal range for SSC/TA. Significant genotype × environment and genotype × month interactions for most fruit chemical traits demonstrate that advanced selections must be tested in multiple environments over multiple time points. It would also be valuable to determine through genetic studies whether recurrent selection could result in genotypes with greater seasonal stability for fruit chemical traits and thereby more consistent flavor. The astringency character in strawberries might be worthy of further investigation by determining the respective role of organic acids and phenolic compounds.

‘Strawberry Festival’ is the dominant strawberry cultivar in west-central Florida, occupying over half of planted acreage at the time of this study. Therefore, it is interesting to note that this cultivar rarely had the most extreme values for any of the traits studied. This illustrates the importance of acceptable performance for many traits, not just a few, in the commercial success of a strawberry cultivar.

Literature Cited


