Is Strawberry Fruit Firmness Associated with Tissue Ca Concentration?

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Several studies have focused on the improvement of strawberry (Fragaria ×ananassa Duch.) fruit firmness with additional calcium (Ca) applications. These studies found conflicting results for additions of Ca when it is applied as soil-applied gypsum or various foliar formulations. Because limited information exists on the association between fruit firmness and tissue Ca concentration in commercial strawberry cultivars, the objective of this study was to determine if leaf or fruit Ca concentration is a reliable predictor of fruit firmness. Leaf and fruit samples for Ca concentration and firmness measurements were determined in Feb. and Mar. 2004 on seven cultivars and correlations were conducted using Pearson’s correlation coefficient. Ca concentration and fruit firmness was significantly different among cultivars. Leaf Ca concentrations ranged between 8,390 (‘Camarosa’) and 11,986 (‘Winter Dawn’) mg·kg⁻¹. Fruit Ca concentrations ranged between 1,572 (‘Winter Dawn’) and 2,550 (‘Sweet Charlie’) mg·kg⁻¹. ‘Treasure’ had the firmest fruits (1.23 N) and ‘Sweet Charlie’ the least firm (0.72 N). There was a wide range in r-values among the correlations, but ‘Camarosa’ had the highest average correlation between fruit Ca concentration and firmness (r = +0.67) and ‘Treasure’ for leaf Ca concentration and fruit firmness (r = +0.29). Based upon this study, no relationship was found between fruit firmness and Ca concentration. Therefore, the practice of applying supplemental Ca to strawberry plants during its normal growing season may not be beneficial to increasing fruit firmness. Moreover, Ca concentration within strawberry plants should not be used as a predictor of fruit firmness or to substitute for firm fruited cultivars used in production in the selection of lines during breeding.

Fruit firmness is one of the most important postharvest characteristics to strawberry growers, shippers and consumers. Firmer fruits have a higher potential of withstanding transport and are less likely to decay. Fruit firmness is affected by plant genetics and growing conditions (Dunn and Able, 2006; Prange and DeEll, 1997). Although the distribution of Ca and other nutrients in strawberry have been characterized (Dunn and Able, 2006; Makus and Morris, 1998), few studies have related the presence of Ca to textural attributes as pointed out by (Dunn and Able, 2006).

Yet, supplemental Ca applications are still commonly done in Florida’s strawberry fruiting fields despite the inconsistent results (Chéour et al., 1990, 1991; Dunn and Able, 2006; Erincik et al., 1998; Makus and Morris, 1989, 1998). None of these studies sufficiently probed into soil levels of Ca, stated Ca sufficiency levels for strawberry production, or used fruits that meet the US quality standards (USDA, 2006). On the contrary, Dunn and Able (2006) suggested that Ca is not mobilized to the fruit tissues, because increasing Ca applications only increased leaf Ca not fruit Ca. The rationale behind the practice of preharvest applications of Ca comes from the physiological activity of Ca in membrane stability (Kirkby and Pilbeam, 1984), namely the linkages between pectic substances within the cell wall (Demarty et al., 1984), and reduced rate of ripening and respiration (Ferguson, 1984). Plus, other commodities such as apple (Malus spp.) and pear (Pyrus spp.) (Neilsen et al., 2005; Raese and Drake, 2006), have successful postharvest improvement with Ca applications. Both of these species are in the same family as strawberry, Rosaceae. Hence, a positive correlation between Ca concentrations within strawberry plant tissues and fruit firmness might be expected.

Many efforts have been made to improve fruit firmness by supplementing with foliar and soil applications of Ca. There are no studies published that have investigated the association between fruit firmness and Ca concentration in strawberry fruit. The objectives of this study were 1) to determine if selected strawberry cultivars have similar Ca concentrations in fruits and leaves; and 2) to correlate these Ca concentrations with fruit firmness during the harvest season to determine if a reliable association exists for the purpose of improving fruit firmness with Ca.

Materials and Methods

Cultivars included both University of California (UC) licensed cultivars of ‘Camarosa’, and ‘Camino Real’, University of Florida (UF) licensed cultivars of ‘Strawberry Festival’ (‘Festival’), ‘Carmine’, ‘Sweet Charlie’, ‘Winter Dawn’ and one cultivar from J&P Research, Inc. from Naples, FL called ‘Treasure’. These cultivars were chosen because they were the most commonly grown cultivars in Florida at the time of the survey. Each cultivar was planted on nine 36-m-long rows located at the University of Florida, Gulf Coast Research and Education Center at Dover, FL.
(GCREC–Dover) on Seffner fine sand (sandy, siliceous, hyperthermic, Quartzipsammentic Haplumbrepts) from Aug. 2003 to Mar. 2004. The soil was fumigated to industry standards of 67:33 methyl bromide:chloropicrin mixture (w:w) at 381.7 kg·ha$^{-1}$. Annual hill production was used with low-density polyethylene film, drip irrigation, beds set 1.2 m on center, and transplants planted in a double row, 0.30 m spaced in row and 0.35 m between rows. All crop management practices followed current recommendations (Peres et al., 2008).

Four replicate samples of 30 recently matured leaves and 10 U.S. No. 1 grade (USDA, 2006) fruits were randomly collected on 16 Feb. 2004 and 17 Mar. 2004. Each sample was collected from an 88-m$^2$ planted area. Leaf and fruit samples for Ca determination were dried in a forced-air oven at 70 °C, and ground to pass through a 20-mesh screen. One gram dried tissue was ashed in a muffle furnace at 500 °C for 4 h, cooled to room temperature, and digested with 6 N HCl with a final solution volume of 50 mL. Ca determination were made with an inductively coupled plasma spectrophotometer (EPA Method 200.7, CIROS, Spectro) (Mylavarapu and Kennelly, 2002). All Ca concentrations were expressed in mg·kg$^{-1}$ based on a dry weight basis.

On 14 Feb. and 14 Mar. 2004, 1.8 kg of strawberry fruits were harvested randomly from the planted area and transported to the UF Postharvest Horticulture Laboratory in Gainesville, FL, for firmness measurements. Each sample date consisted of four replications of ten U.S. No. 1 fruit each selected from the cultivar population. Samples were stored at 1 °C for no more than 2 h until the destructive test was performed. Preparation for firmness measurements consisted of removing an 11-mm slice from the equatorial section of each fruit at room temperature. Each slice was orientated flat (proximal end up) for firmness mechanical resistance measurements. Measurements (recorded in Newtons, N) were taken using a penetrometer (Instron Universal Testing Instrument, Model 4411, Canton, MA) with a 5-kg load cell fitted with a 4-mm convex probe with a crosshead speed of 5 cm·min$^{-1}$ to a maximum depth of 7 mm. Two measurements were taken within the cortex tissue of each fruit slice and maximum force (bioyield point) was used to determine fruit firmness of each sample.

Calcium concentration and fruit firmness measurements were subjected to ANOVA for cultivar effects using a general linear model (SAS, 2000) as a completely randomized design and mean separation by Fisher’s least significant difference, lower case letters denoting differences. The coefficient of variation (cv) was calculated as one hundred times the ratio between the standard deviation and the mean and was reported for each variable. Correlations between fruit and leaf Ca concentration and firmness for February and, March harvests, and season average were calculated using Pearson’s correlation coefficients and $P$-values.

**Results and Discussion**

Leaf and fruit Ca concentrations were different for the two sample dates, however, there were no interactions between month and cultivar for either leaf or fruit Ca concentration ($P = 0.08$ and 0.24, respectively) (Table 1). For both sampling dates, ‘Winter Dawn’ had the highest leaf Ca concentration within leaf tissues (13, 068 and 12,472 mg·kg$^{-1}$). This cultivar was similar to ‘Carmine’ in March (10,220 mg·kg$^{-1}$), but not in February for leaf Ca concentration. Cultivars with the lowest leaf Ca concentration were ‘Camarosa’, and ‘Treasure’ in February (6559 and 8102 mg·kg$^{-1}$, respectively), ‘Strawberry Festival’, and ‘Treasure’ in March (9360 and 8835 mg·kg$^{-1}$, respectively). ‘Winter Dawn’ had the lowest leaf Ca concentration for the sampling dates (1572 and 1175 mg·kg$^{-1}$), but the highest leaf Ca concentration (13,068 and 12,472 mg·kg$^{-1}$). This was an unexpected result, since the conventional wisdom is that if leaf Ca concentration increased, fruit Ca will also increase. These results further support the suggestion that Ca is not mobilized to fruit tissues by Ca applications (Dunn and Able, 2006). Sampling date was nonsignificant for fruit Ca concentration, and therefore, both sampling dates were considered to be the same. There were differences among the cultivars for fruit Ca concentration. The average Ca concentration across sampling dates for ‘Camino Real’, ‘Camarosa’, and ‘Winter Dawn’ were all similar (1489.5, 1488.5, and 1373.5 mg·kg$^{-1}$), but ‘Sweet Charlie’ was not similar to these cultivars for fruit Ca concentration (2119.5 mg·kg$^{-1}$).

There was a significant interaction between sampling date and cultivar for fruit firmness measurements ($P = 0.04$ (Table 2).)

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**Table 1. Calcium concentration in leaf and fruit tissue of selected strawberry cultivars in the 2003–04 season.**

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>February</th>
<th>March</th>
<th>Leaves</th>
<th>Fruit</th>
<th>Leaves</th>
<th>Fruit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treasure</td>
<td>8102 d</td>
<td>2447 ab</td>
<td>8835 d</td>
<td>1987 a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strawberry Festival</td>
<td>8588 cd</td>
<td>2360 ab</td>
<td>9360 cd</td>
<td>1778 ab</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Camino Real</td>
<td>8266 bcd</td>
<td>1506 c</td>
<td>10595 bc</td>
<td>1473 bc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carmine</td>
<td>8132 bc</td>
<td>2186 b</td>
<td>11340 ab</td>
<td>1606 abc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Camarosa</td>
<td>6559 d</td>
<td>1612 c</td>
<td>10220 bcd</td>
<td>1365 bc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweet Charlie</td>
<td>11056 b</td>
<td>2250 a</td>
<td>10000 bcd</td>
<td>1959 a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter Dawn</td>
<td>13068 a</td>
<td>1572 c</td>
<td>12472 a</td>
<td>1175 c</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*CV* (%)$^y$  7 13 11 18

LSD$^y$  936 3380 1706 457

Mean separation by Fisher’s least significant difference, lower case letters denoting differences.

**Table 2. Fruit firmness for selected strawberry cultivars during 2003–04 season.**

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>February</th>
<th>March</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treasure</td>
<td>1.23 a</td>
<td>1.13 a</td>
</tr>
<tr>
<td>Strawberry Festival</td>
<td>1.14 ab</td>
<td>0.96 bc</td>
</tr>
<tr>
<td>Camino Real</td>
<td>1.10 b</td>
<td>1.01 abc</td>
</tr>
<tr>
<td>Carmine</td>
<td>1.07 b</td>
<td>1.04 ab</td>
</tr>
<tr>
<td>Camarosa</td>
<td>0.90 c</td>
<td>0.99 bc</td>
</tr>
<tr>
<td>Sweet Charlie</td>
<td>0.72 d</td>
<td>0.71 d</td>
</tr>
<tr>
<td>Winter Dawn</td>
<td>0.85 c</td>
<td>0.88 c</td>
</tr>
</tbody>
</table>

*CV* (%)$^y$  8 18

LSD$^y$  0.130 0.128

Mean separation by Fisher’s least significant difference, lower case letters denoting differences.
and fruit firmness \((r = +0.29)\), as averaged across the two sampling dates. Many correlations were strongly negative or lacked strong associations \((r < 0.70)\) between Ca concentration and fruit firmness. The negative correlations suggest that increasing Ca of strawberry fruit could be detrimental to fruit firmness. The exception to this was ‘Treasure’, which had the only significant correlation between any plant tissue and fruit firmness (Fig. 1A). This correlation was significant only for the March sampling date, which emphasizes the variability of the correlations. All other cultivars had correlations that were nonsignificant for either sampling date. Averaging over all cultivars, the only significant correlation was between leaf Ca concentration and fruit firmness \((r = –0.37)\) (Fig. 1B). Yet, this correlation followed the trend of a negative weak association.

These results do not support the common belief that applying supplemental Ca to strawberry fruit will increase firmness. Previous studies have been inconsistent on the effects of foliar Ca applications on increased fruit firmness. Yet, these previous studies have relied upon positive results in other commodities to validate their hypothesis for strawberry. Based upon this study’s findings, leaf and fruit Ca concentration cannot be used to predict fruit firmness for the selected cultivars. These characteristics are apparently independent of each other and not linked. It is possible that other factors (such as cell wall degrading enzymes) are also responsible for fruit firmness.

Based upon this study, no relationships were found between Ca concentration and firmness for the strawberry cultivars selected. Calcium concentration and firmness characteristics were found to be cultivar-dependent. The UF strawberry-breeding program has cultivars that had similar Ca concentration and fruit firmness. Similarities in parent lines for the UF strawberry-breeding program may be responsible for these results. Calcium concentrations of fruit or leaves were not factors in determining firmness in any of the cultivars. ‘Treasure’ was an exception within the population to be cultivar-dependent. The UF strawberry-breeding program has cultivars that had similar Ca concentration and fruit firmness. Similarities in parent lines for the UF strawberry-breeding program may be responsible for these results. Calcium concentrations of strawberry leaf or fruit tissue is not a practical method for breeders to determine fruit quality.

**Literature Cited**


