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DELAYS TO COOLING AND POSTHARVEST QUALITY OF FRESH, FLORIDA BLUEBERRIES

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Abstract. **Production of fresh blueberries continues to increase in Florida due to the high price obtained for the early season crop. The fruits are shipped to distant markets in North America and as far away as the Pacific Rim. Following harvest, blueberries are often transported to off-farm facilities for grading, packing and cooling. Growers have become increasingly aware that postharvest quality can be extended if forced-air cooling is applied shortly after harvest. However, delays due to harvest and transport from the field may negate the advantages of such a system. In spring 2000 'Bonita' blueberries (*Vaccinium ashei* Reade), a rabbiteye type, were subjected to delays-to-cooling at 30°C (86°F) of 0, 2, 4, 6 and 8 hr followed by storage for 1 to 4 weeks in clamshells at 2°C (34 °F) and 90% relative humidity (RH) to simulate commercial handling. Fruit quality (appearance, weight loss, firmness, decay and composition) was evaluated weekly during 4 weeks, following transfer to 20°C (68°F) for 24 hr prior to each evaluation. Weight losses were directly proportional to delays-to-cooling and, combined with appearance, seemed to be the best quality parameters to indicate losses in quality. A firmness index obtained through compression of whole fruit based on 1 mm total deformation was more sensitive to detect firmness variation than for deformations of 2 or 3 mm. In general, no quality differences were observed for 'Bonita' blueberries regarding delays-to-cooling effect, but there were significant differences within storage time. Further delay-to-cooling investigations should be carried out for early season, highbush blueberries.**

Florida was ranked seventh in highbush blueberry production in North America with about 2000 acres (800 ha) of cultivated area, and fifth in terms of value (P. Lyrene, pers. comm.; Williamson and Lyrene, 1995). The main appeal for

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Florida's growers is the early season, high-priced market in April. During the past five-year period, the total area of blueberry production has remained constant, however, rabbiteye-type blueberries have consistently been replaced by early season, highbush-type berries. High prices are obtained for the early season crop and the fruits are shipped to distant markets in North American and as far away as the Pacific Rim.

Following harvest, blueberries are often transported to off-farm facilities for grading, packing and cooling. Growers have become increasingly aware that postharvest quality can be extended if rapid cooling is applied shortly after harvest (Talbot et al., 1992; Boyette, 1996). The availability of forced-air cooling and cold room facilities at farm level has the potential to further extend fruit quality and postharvest life. However, delays due to harvest and transport from the field may negate the advantages of such a system. Even though many studies have been reported in the last 30 years concerning the effects of temperature management and storage on postharvest quality, no one has specifically addressed the quality problems associated with delays to cooling fresh blueberries. Jackson et al. (1999) and Nunes et al. (1996) addressed the same problem for lowbush blueberries and strawberries, respectively, from whose work part of the methodology for this study was derived. The main objective of this work was to detect changes in quality of blueberries subjected to several delays to rapid cooling in order to provide decision-making parameters for managers of cooling facilities. An additional objective was to investigate the sensitivity of present quality parameters in detecting quality changes in blueberries, specifically the firmness index. Various authors have used this parameter in various ways, and there is a question as to how fruit-to-fruit variability and amount of deformation affect firmness index values.

Materials and Methods

Fruits of 'Bonita' rabbiteye blueberries (*Vaccinium ashei* Reade) were carefully hand-picked on June 14, 2000, at a Gainesville-area farm and were stored overnight in plastic lugs at 2°C and 90% relative humidity (RH). The following morning they were removed from the cold room and spread out on shallow trays until the pulp reached ambient air temperature of 20°C. Berries were then individually sorted by weight and berries weighing 1.4 to 1.6 g were chosen for the experiment since they represented the average berry size of the harvested lot and fell within commercial size. Prior to application of the delay-to-cooling treatments, 800 of these berries were randomly distributed in 20 clamshells containing 40 berries each. The diameters of the fruits were measured at the equator and the filled clamshells were weighed.

Cooling delay times, rapid cooling and time-temperature history. All 20 clamshells were transferred to 30°C (50% RH) until pulp temperature reached equilibrium. This was done in order to expose the fruits to common handling temperatures. The clamshells were kept open during this warm-up time and pulp temperature was measured using thermistor probes and a recording device (Squirrel 1200 series data logger, Science Electronics, Dayton, OH). The probes were inserted radially into the berry pulp and positioned approximately in the center of the berry.

At equilibrium temperature five clamshells were transferred back to 2°C, where the berries were submitted to forced-air cooling. When the pulp temperature reached 4°C, the cooling process was complete and the clamshells were stored at the same temperature. This procedure was repeated for the remaining clamshells to obtain five cooling delay times of 0, 2, 4, 6 and 8 hours, referred in this paper as treatments T0, T2, T4, T6 and T8, respectively. The clamshells were kept in storage during a four-week period in which quality evaluations took place weekly.

Additional warm up and weekly evaluations. After every storage week, one clamshell from each of the five treatments was placed in a sealed plastic bag to avoid condensation and transferred to 20°C. After one hour the bag was removed and the clamshell kept at 20°C and 68% RH for an extra 24-hour period to simulate retail conditions. At the end of this 24-hour period the clamshells were weighed followed by a subjective appearance evaluation. The appearance attributes considered were sunken areas, decay and shrivel leading to classifying each berry into two categories: commercially accepted or commercially not accepted. Next, firmness measurements were performed by individual compression of the whole fruit between two flat, parallel plates (ASAE, 1984) at a constant deformation rate of 50 mm/min using an Instron Testing Machine (Model 4411, Canton, MA) equipped with a 50 N load cell. Each berry was positioned on its equator between the plates, setting the initial position (zero deformation) at contact between fruit and plate surfaces. Although some researchers (Mohsenin, 1980; NeSmith et al., 1999; Slaughter and Rohrbach, 1985; Timm et al., 1996) have reported the firmness index in terms of chord stiffness, in this study the index is reported as the force value at a certain deformation. This was done to investigate the influence of deformation on the firmness index. Force values were recorded at 1, 2 and 3 mm total deformation. After firmness measurements, the fruits were frozen for later determination of several quality parameters.

Other quality parameters. At the completion of the four-week storage period, these quality parameters were determined: soluble solids content (SSC), total titratable acidity (TTA), pH, and sugar/acid ratio. For these analyses, the fruits were thawed and homogenized using a Polytron (Brinkmann, Polytron homogenizers, Westbury, NY). The homogenate was centrifuged at 15000 RPM for 20 min. The supernatant was then filtered using cheesecloth. The supernatant was frozen for later measurements. Samples were prepared using ten fruit per replicate for each of the analyses. For Total Soluble Solids, the supernatant as prepared above was placed on the prism of a digital refractometer (Reichert-Jung, Mark Abbe II Refractometer, Model 10480, Depew, NY) and the soluble solids content (SSC) measured in °Brix. The pH was determined using the same supernatant described above with a pH meter (Corning Scientific Instruments, pH meter 140, Medfield, MA) standardized with pH 4.0 and 7.0 buffers. For total titratable acidity, 2 g of the sample supernatant was weighed out and diluted in 50 ml of distilled water. The samples were analyzed on an automatic titrimeter (Fisher Titrimeter II, No. 9-313-10, Pittsburgh, PA) and titrated with 0.1 N NaOH to an endpoint of ph 8.2. The volume of NaOH required to reach the endpoint was recorded and % TTA was calculated by using the following equation:

$$\% \text{ acid} = [(\text{vol. of NaOH (ml)} * \text{Normality (NaOH)} * 0.064) / (\text{2g of Juice})] * 100$$

Where: 0.064 = milliequivalent factor for citric acid.

Initial evaluation. All quality parameters determinations were performed for an additional group of 40 berries on the initial day of the experiment.

Statistics and analysis. All data were subjected to analysis of variance and treatment means were compared using Duncan's Multiple Range Test, P < 0.05 (SAS software, release 6.12, SAS Institute Inc. Cary, NC, USA).

Results and Discussion

Initial quality characteristics of the berries. Initially, the berries showed no shriveling, no stem-end leakage, and reasonably good epicuticular wax ("bloom"). They had commercially acceptable size with average equator diameter of 13.9 mm (SD = 0.3 mm; n = 25 berries) and average firmness index of 1.28 N (SD = 0.34 N; at 1-mm deformation). The average value for soluble solids concentration was 16.5 °Brix (SD = 0.54°Brix), titratable acidity 0.54% (SD = 0.05%) and sugar/acid ratio of 30.68 (SD = 1.9) (Table 1).

Appearance. The results of weekly appearance evaluations over the storage period of 4 weeks are shown (Table 2). No decay was observed in any of the treatments. No differences were observed among treatments in the first two weeks, even though on week 2 most berries already showed slight signs of shriveling. It is evident that a storage period between two and three weeks resulted in serious increases in sunken areas and shrivel, causing rejections based on these criteria to rise to unacceptable values as high as 50%. Some results are unclear, for example, shrivel levels for no delay and 2-hr delay actually decreased between weeks 3 and 4, from 50% to 42.5% and from 47.5% to 22.5%, respectively. This decrease may be attributed to variability among berries in the selected lot, difficulties in harvesting berries at the same maturity stage and subjective experimental decisions. Treatment differences were only clearly differentiated at week 4 when rejection values reached 47.5%, 60% and 70%, corresponding to 4-, 6- and 8-hr delays. No decay was observed in any of the treatments.

Weight loss. Results of weight loss are presented as percentage of the initial weight. As expected, weight loss increased as delay-to-cooling increased. Weight loss values for T0 were 1.9, 4.0, 4.4, and 5.3%, and for T8 were 3.8, 5.3, 5.4, and 7.4% for storage periods of 1, 2, 3 and 4 weeks, respectively (Fig. 1). All the other treatments fell between these two treatments and followed the same pattern. The only exception was one value of 5.4% at week 3 for T8, which was less than the values for treatment T6 and T4. In general, weight losses were unacceptably high for commercial operations. Weight losses between 1 and 2% for 'Bonita' blueberry, as reported by Miller et al. (1988) for the first two weeks of storage, would be more acceptable. The excessive weight losses encountered in this study probably occurred during the additional 24-hour period at 20°C and 50% RH.

Table 1. Average values of SSC, TTA, pH and sugar/acid ratio for 'Bonita' blueberry during 4 weeks of storage.

	Initial	Week 1	Week 2	Week 3	Week 4
SSC (°Brix)	16.5 c[z]	17.44 b	17.53 b	18.57 a	18.74 a
TTA (%)	0.54 b	0.64 ab	0.56 b	0.60 ab	0.73 a
pH	3.23 a	3.22 a	3.28 a	3.30 a	3.24 a
Sugar/acid	30.68 a	29.25 a	31.64 a	32.26 a	27.42 a

[z]Means with the same letter within rows are not significantly different according to 'Duncan's Multiple Range Test (P < 0.05).

Table 2. Effect of delay-to-cooling on incidence of unmarketable fruits (%) during 4 weeks of storage.

Delays to cooling (hr)	Week 1 (%)	Week 2 (%)	Week 3 (%)	Week 4 (%)
0	0	0	50.5	42.5
2	0	0	47.5	22.5
4	0	0	40.0	47.5
6	0	0	35.0	60.0
8	0	0	27.5	70.0

Defining the firmness index. To compare the force values obtained from the three deformations (1, 2 and 3 mm), mean force values measured weekly during 4 weeks storage were expressed as a percentage of the initial values (Fig. 2). Force values measured at 1 mm deformation showed a greater span between initial and week 4 measurements than did those force values obtained from 2 or 3 mm deformation. At 1 mm deformation, the force decreased to 37% of the initial value, while it decreased to 48% and 59% at 2 and 3 mm deformation, respectively. Therefore, in this paper the firmness index is expressed as the force value (N) obtained at 1 mm deformation, which is more likely to detect smaller variations in the force-deformation curve.

Firmness index. Firmness index average values varied from 1.28 N for the initial conditions to 0.65 N for T8 at week 4, the most severe treatment (Fig. 3). No significant treatment differences were found at each evaluation period (Duncan's Multiple Range Test, P < 0.05). This suggests that firmness index was not greatly affected by delays-to-cooling treatments. On the other hand, there were significant differences between storage periods, except for weeks 3 and 4 (26.9%, 37.9%, 51.6%, 53.3% for weeks 1, 2, 3 and 4, respectively). In this study, it was found that decreasing firmness index values during storage correlated with increasing water loss, as reported by Mohsenin (1980). Even the small variations in the firmness index which occurred between the 3rd and 4th weeks corresponded with small differences in weight loss.

Other quality parameters. SSC, TTA, pH and sugar/acid ratio showed no difference among treatments (Duncan's Multiple Range Test, P < 0.05). For this reason treatments were pooled and reported as average values (Table 1). These values were transformed as percentage of the initial value at the

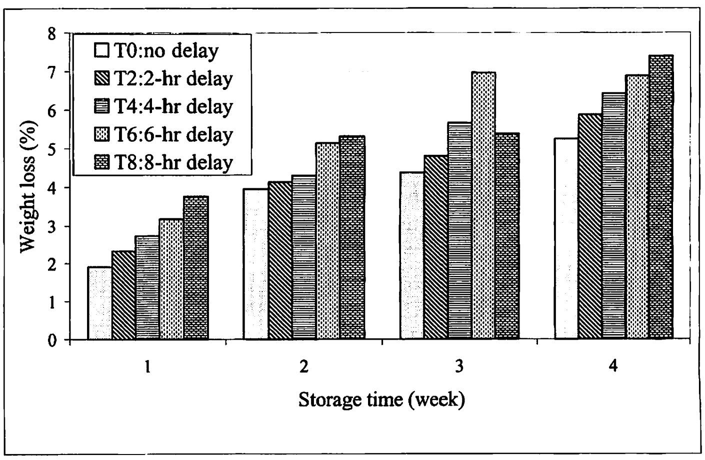

Figure 1. Effect of delay-to-cooling on percentage of weight loss during storage of 'Bonita' blueberries.

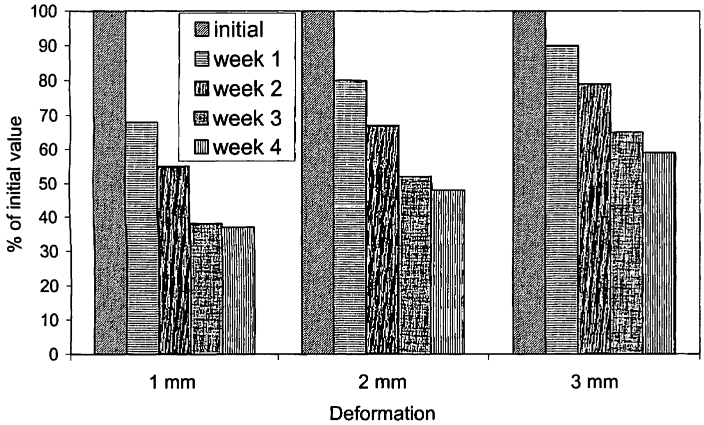

Figure 2. Percentage of initial average force values obtained through compression of 'Bonita' blueberries between parallel plates (at 1, 2 and 3 mm total deformation) during 4 weeks of storage.

initial day (Fig. 4). Negative values represent variations below initial values. SSC values increased linearly over time from 16.5 to 18.74 °Brix and may be attributed to weight loss. TTA values ranged from 0.54% to 0.73%. pH values ranged from 3.22 to 3.3 and showed the least deviation from the initial value ranging from 0.3% to 2.1%. TTA and pH values agree with those reported by Miller et al. (1988) for 'Bonita' blueberry. Sugar-to-acid ratio was also relatively constant over the storage period ranging from 27.42 to 32.26, showing deviations from the initial value not above 5.2% except for week 4 when it reached the value of -10.6%.

Conclusions

There were no significant differences in postharvest quality parameters of 'Bonita' (rabbiteye) blueberries when held at 30°C for up to 8-hour before cooling. Fruits maintained acceptable appearance for two weeks when stored at 2°C and 90% RH. However, increased delays-to-cooling increased weight loss, suggesting that weight loss may be the best indicator of quality change during storage. The firmness index was most sensitive to textural changes when calculated using

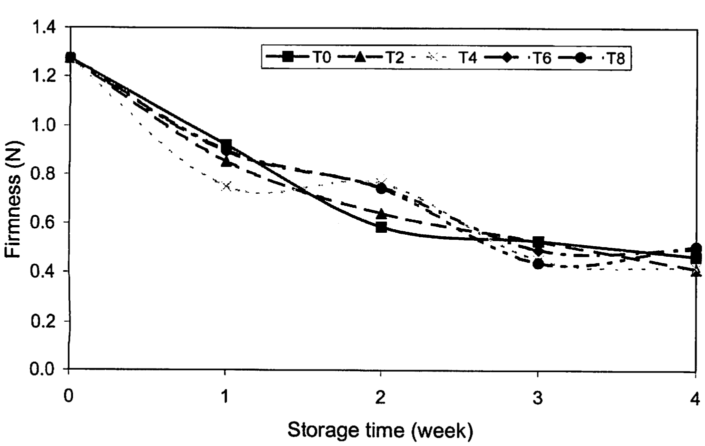

Figure 3. Firmness index values for 'Bonita' blueberries during 4 weeks of storage (subjected to 0, 2, 4, 6, or 8-hr delays prior to cooling).

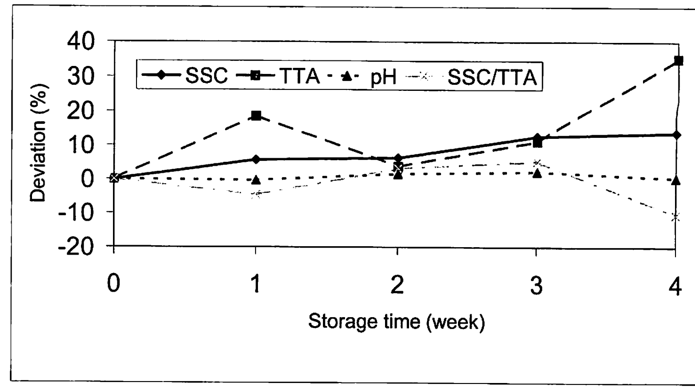

Figure 4. Deviation from initial value (%) of SSC, TTA, pH and sugar/acid ratio for 'Bonita' blueberries over a 4-week storage period.

1 mm total deformation. Since Florida growers are replacing rabbiteye-type blueberries with early season, higher-value, highbush-type varieties, similar experiments should be conducted on this latter type to determine the effects of delays to cooling on postharvest quality.

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