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Development of an Integrated System to Rinse, Sanitize, and Cool Fresh-market Strawberries

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Strawberries were commercially harvested into clamshells and evaluated for quality after cooling by either forced-air cooling or hydrocooling. Forced-air cooling (FA) was accomplished in commercial cooling tunnels (clamshells in corrugated cartons) for approximately 60 minutes. For hydrocooling (HY), individual clamshells were immersed for 15 minutes in an agitated, ice-water bath with 200 ppm chlorine, briefly drained, then placed in returnable plastic containers (RPCs). Cartons and RPCs were stacked on separate pallets and stored in a commercial cold room for 14 days at 1 °C (34 °F). Whole clamshell subsamples were graded on-site for fresh appearance after 7 and 14 days, and subsamples were transported to the Postharvest Horticulture Laboratory in Gainesville, FL, where fruit was stored overnight at 1 °C for subsequent evaluations (pulp firmness, appearance, marketable berries, soluble solids content and titratable acidity) conducted on days 8 and 15. There was no difference in FA or HY fruit quality under the conditions used in this experiment. These results indicate that HY had no detrimental effect on the fruit quality parameters measured and has the potential to maintain quality and offer a sanitized product that is currently unavailable on the market.

In 2013, U.S. strawberry production was about 1.36 million metric tons and 23,549 ha (58,190 acres) were harvested (FAO, 2014). The top strawberry-producing states were California, Florida, and Oregon (USDA, ERS, 2012). During the 2013 season, Florida production was 24,640 pounds (~11 t) per acre.

Since strawberries are susceptible to mechanical injury they are typically hand harvested directly into containers for retail. Forced-air cooling (FA) and subsequent cold storage is the traditional method used to maintain quality in commercial strawberry production. Previous research has shown that the interval between harvest and cooling is critical because delays in this process increase losses due to shrivel and softening (Nunes et al., 1995). Nunes et al. (2005) also reported an 18% decrease in storage decay when strawberries were cooled within 1 h of harvest compared to those cooled after a six-h delay. To achieve recommended $T_{7/8}$ cooling, (time required for the product to undergo a temperature drop equal to 7/8 of the difference between the initial product temperature and the temperature of the air entering the system), strawberries are commercially FA cooled for about 1 h.

Several small-scale studies have shown benefits of hydrocooling (HY) strawberries, with the most obvious being reduced cooling time, about 12 min (Ferreira et al. 1996; Jacomino, 2011). Ferreira et al. (2006) demonstrated that HY fruit stored at various temperatures for 8 or 15 d had higher quality than FA strawberries, primarily better epidermal color and lower weight loss and decay incidence. According to Ferreira et al. (2009), HY also shows promise to rapidly cool strawberry fruit while reducing weight loss and bruising. Jacomino et al. (2011) confirmed that HY resulted in less weight loss, higher firmness and did not promote decay in strawberries during storage as compared to those subjected to FA.

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The objective of the current study was to conduct a semi-commercial scale HY test and evaluate potential effects on strawberry quality.

Materials and Methods

Strawberry fruit (unknown cultivar) were obtained from a commercial farm near Plant City, FL, late in the season (15 Mar. 2012). Fruit were harvested into clamshells and placed in corrugated fiberboard by commercial crews. The fruit was then transported to a central cooling facility on a commercial truck within 2 h of harvest.

Initial berry pulp temperature was 22 °C (72 °F). Berries were cooled by either FA or HY. FA was conducted in a commercial cooler under standard industry practices with a pressure drop of 0.6 inches water (1 °C, or 34 °F, 1 h duration). Berry pulp temperature after cooling was 0.4 °C (32.7 °F). After FA, 20 corrugated flats with eight, 1-lb clamshells each were stacked on a pallet five layers high (8 flats/layer). For HY, 10 clamshells were placed in a single-layer, 16-gauge, vinyl-coated wire cage that allowed adequate water circulation. Chlorinated water (200 $mg \cdot L^{-1}$ free chlorine, pH 6) was maintained at 1 °C to 2 °C (35.6 °F) within insulated containers with a surrounding air temperature of 23 °C (73.4 °F). Ice and sanitizer were added to the water as needed to maintain constant conditions and the cages were gently agitated manually to promote thorough water circulation during the 15-min cooling period. Following cooling the clamshells were briefly drained, and then placed in pre-wetted RPCs (9/flat) to simulate immersion of whole flats. Berries were stored in a 4 °C (39.2 °F) staging area until all berries were HY cooled. The RPC flats were then stacked on a pallet (5/layer) four layers high.

Fruit from each treatment were stored on separate pallets for 14 d in commercial storage at 1 °C (33.8 °F) and 63% relative

humidity (RH). After 7 and 14 d of storage, subsamples (n=12 clamshells/treatment) were taken from top, middle and lower layers within the pallet to determine if location had an impact on fruit quality. The subsamples were then transported in insulated containers with ice to the Postharvest Horticulture Laboratory at the University of Florida in Gainesville and stored overnight at 1 °C (33.8 °F).

The following day quality assessments were conducted. Whole clamshells were rated for overall appearance according to the following 9-point scale: 9 = excellent: full fresh appearance, high sheen; 7 = good: still looks fresh, still shiny; 5 = fair: not fresh appearance, low sheen, limit of marketability; 3 = poor: dull, limit of usability; and 1 = extremely poor: shriveled appearance. Fruit showing decay symptoms were recorded and reported as percent decay.

Pulp firmness (n=3 berries/clamshell; 12 clamshells/treatment) was determined using a Texture Analyzer (model TA.HD plus; Texture Technologies Corp, Scarsdale, N.Y.), with a 5-kg load cell, crosshead speed of 10 cm/min and a 4-mm diameter convex probe. The maximum (bioyield) force necessary to penetrate 6 mm into the pulp was determined and expressed in Newtons (N).

From the remaining sound fruit, 10 strawberries per clamshell were frozen in vapor-barrier bags at –30 °C. After 12 weeks, samples were thawed, homogenized and centrifuged at 17,600 g_n for 20 minutes at 5 °C (41 °F). The supernatant was filtered through cheesecloth and the juice was used to assess soluble solids content (SSC) and total titratable acidity (TTA). SSC was determined by placing several drops of juice on the prism of a digital handheld refractometer (model AR200, Reichert Analytical Instruments, Depew, NY) and reported as °Brix. The TTA was determined with an automatic titrimeter (model 719 S Titrino; Metrohm, Herisau, Switzerland). The TTA was determined by diluting 6 g of strawberry juice with 50 ml deionized water then titrating with 0.1 N sodium hydroxide (NaOH) to an endpoint of pH 8.2 and expressed as percent citric acid. SSC/TTA ratios were subsequently calculated.

Data was sorted and analyzed according to location (top, middle, and lower) within the pallet. Experiments were performed using a completely randomized design, according to a factorial scheme where the variations were cooling methods and storage times. Data were analyzed using ANOVA and means were compared using Duncan's Multiple Range Test ($P < 0.05$) (SAS, version 9.2; SAS Institute, Cary, NC).

Results and Discussion

Strawberry appearance ratings were similar at each sampling time, regardless of cooling method or sample location within the pallet. However, appearance ratings decreased significantly from 8 after 7 d storage to 6 after 14 d (Fig. 1). These results are comparable to those found by Jacomino et al. (2011), where 'Strawberry Festival' fruit cooled by either FA or HY had similar appearance ratings after 7 d at 1 °C + 7 d at 5 °C + 2 d at 20 °C.

HY fruit were consistently firmer than FA fruit for all locations at both storage periods, with the exception of those located in the pallet middle after 7 d (Fig. 2). There were greater differences in firmness at 14 d, particularly for fruit located in the middle and bottom layers. Since both FA and HY fruit after 14 d were softer when stored at lower layers the most likely cause was senescence. In a previous study, FA and HY strawberries maintained similar firmness values (1.13 to 1.37 N) throughout 14 d storage

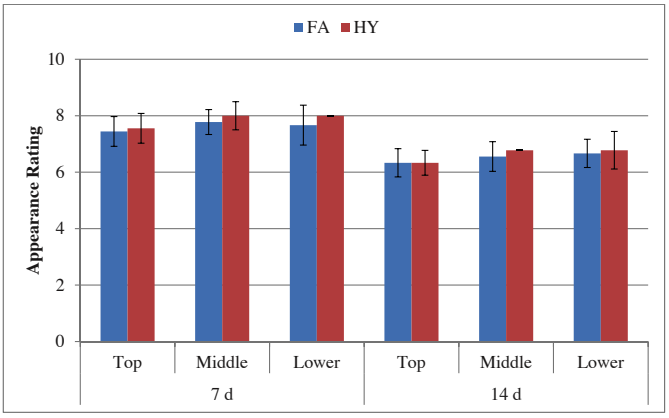

Fig. 1. Appearance ratings of FA or HY strawberries located in the top, middle and lower layers of the pallet during 14 d storage at 1 °C. (n=4 reps of 31 to 42 fruit each).

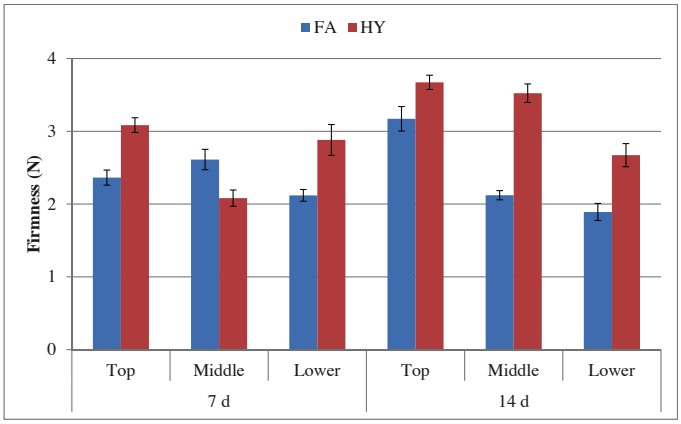

Fig. 2. Firmness of FA and HY strawberries located in the top, middle and lower layers of the pallet during 14 d storage at 1 °C. Values represent the mean (n=12 fruit).

(Jacomino et al., 2011). In the current study as well as previous studies firmness results might have been easier to differentiate if evaluated at shorter intervals (less than 7 d).

There were no significant differences SSC/TTA ratios for any of the treatments; ratios ranged from 10.9 to 12.6 (Fig. 3). The average SSC after 7 and 14 d was 5.8% and 5.6% for FA and a constant 5.3% for HY strawberries (data not shown). The TTA was consistently 0.5% for FA and HY throughout storage (data not shown). This data is consistent with previous studies that also showed no change in SSC or TTA after HY treatment (Jacomino et al., 2011).

Incidence of decay increased from about 6% to 20% between days 7 and 14 (Fig. 4). However, due to sample variability there were no significant differences between treatments. When strawberries were harvested early in the 2010 season, no decay was observed after 14 d at 1 °C (34 °F) for either cooling method (Jacomino et al., 2011). Ferreira et al. (2006) observed lower decay in HY strawberry treated under similar conditions. The higher decay incidence in the current study is most likely due to the late-season harvest. It is not uncommon for commercial strawberry operations to stop applying fungicide toward the end of season as fruit prices decrease.

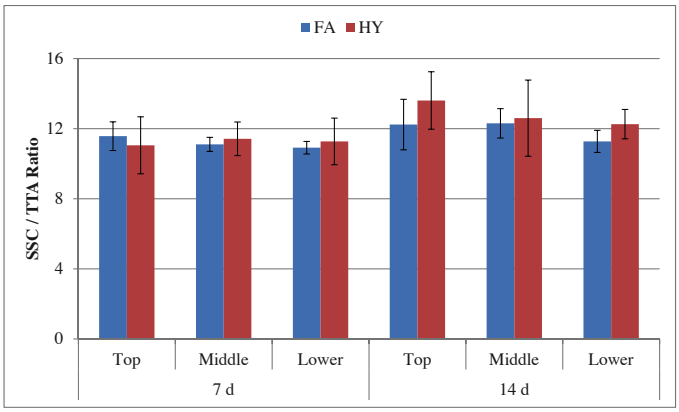

Fig. 3. SSC/TTA ratios of FA and HY strawberries located in the top, middle and lower layers of the pallet during 14 d storage at 1 °C. Values represent the mean (n=4 reps of 10 fruit).

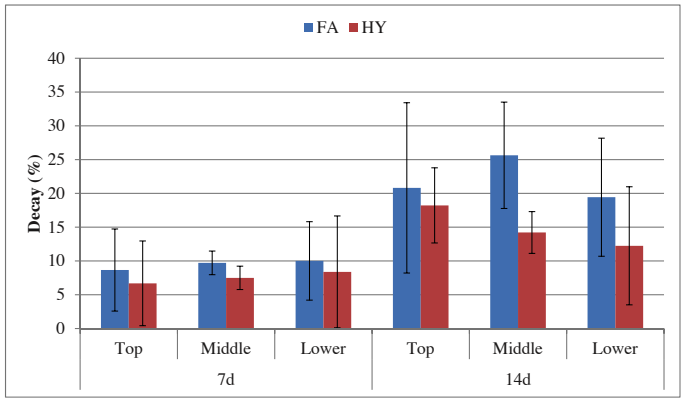

Fig. 4. Incidence of decay of FA and HY strawberries located in the top, middle and lower layers of the pallet during 14 d storage at 1 °C. Values represent the mean (n=4 reps of 31 to 42 fruit each).

This research confirms the results of previous small scale strawberry HY tests. Fruit firmness was better maintained with HY without increasing incidence of decay as compared to fruit cooled by FA. This large scale test was critical in determining the effect of HY on berry quality at various positions in the pallet. Although, free water remained underneath HY clamshells (in top, middle and lower layers) and on top of clamshells (in middle and lower layers), there were no significant decreases in quality compared to FA. Further experiments are planned on a commercial-scale to determine the effect of HY and FA on key quality parameters, sanitization, and technical feasibility.

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