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Potential for Grading, Sanitizing, and Hydrocooling Fresh Strawberries

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Strawberries are currently field-packed into consumer containers and as a result, growers are not able to sell a product that has been rinsed with sanitized water or sorted to exceed minimal grade standards. The current strawberry cooling method is forced-air, which typically takes 1 to 2 h and can result in non-uniform fruit temperature within a pallet. New methods and technologies have the potential to permit growers to grade, pack, rinse, sanitize, and hydrocool uniformly at a central facility. 'Festival' strawberries were commercially harvested in early morning and 7/8-cooled the same day by forced-air in clamshells or by immersion hydrocooling in small baskets. Forced-air-cooling required about 1 h, whereas hydrocooling with chlorine (200 ppm) required 13 min. During 16 d storage in clamshells (7 d at 1 °C, 7 d at 5 °C, and 2 d at 20 °C), there was no decay in fruit cooled by either method. Hydrocooled fruit retained more weight (2% to 5%) than forced-air-cooled fruit. Firmness ranged from 1.1 to 1.4 N, but there were no differences due to cooling treatments. Fruit from both cooling methods remained shiny and had green, turgid calyxes during cold storage; however, after 2 d at 20 °C the fruit became dull with wilted calyxes. Bruise incidence was higher in hydrocooled fruit due to additional handling during the cooling process. Hydrocooling could be a viable cooling option for strawberries that also provides an opportunity to sanitize and grade the fruit; however, further experiments are necessary to optimize this process.

Introduction

Strawberries are a high-value crop with high consumer demand; however, their susceptibility to mechanical damage has led growers to harvest and field-pack unwashed fruit into consumer containers to minimize handling steps. As a result, growers are limited to selling a single product that meets minimal grade standards.

Although Florida strawberry growers receive the highest prices due to off-season production, they could further increase sales in the North American market by providing additional value-added, fresh-market products. There is great potential to adopt new methods and technologies that would allow growers to pack their fruit at a central facility. Eliminating field packing would allow growers to sort and pack strawberries into several grades and new types of packages, thereby expanding sales to meet niche market demands for innovative products.

Strawberries are usually harvested full red and rapidly deteriorate. They are currently field packed into clamshells, palletized, and forced-air-cooled to 2 to 3 °C. Rapid cooling and maintenance of the low pulp temperature are the most important factors to extend the shelf life, protecting the fruit from decay and overripening (Mitcham and Mitchell, 2002). According to Mitchell et al. (1996) cooling should begin no more than 1 h after picking in order to prevent postharvest losses. Nunes et al. (2005) compared strawberry 'Chandler' air-cooled for 1 h (prompt cooling) and 6 h (delayed cooling) after harvesting. Delayed cooling increased incidence of decay 18% and decay severity 30%.

The 7/8 cooling time to cool strawberries by forced-air cooling (i.e., the time to reduce the fruit temperature by 7/8ths of the difference between the initial fruit temperature and the cooling medium temperature) can vary between 0.8 and 1.2 h depending on the design and size of the package, number of vent openings and type of corrugated fiberboard carton (flat), among other aspects (Talbot et al., 1995). According to Mitcham and Mitchell (2002) the 7/8 cooling time can vary between 1.5 and 4 h depending on the air flow characteristics. Moreover the cooling is not uniform inside the pallet. It takes longer to cool fruit located in the middle of the pallet and it is common to find more decayed fruit in the clamshells from this area of the pallet. Also, the plastic clamshell packages work as a barrier to cold air flow despite venting.

Another aspect to be considered is the weight loss, which depends mainly on cooling time and relative humidity (RH) inside the cold room. Talbot et al. (1995) reported around 1% weight loss during strawberry forced-air cooling with 80% to 85% RH.

It has been assumed that the only method to cool strawberries is by forced-air due to a general sense that wetting strawberries after harvest increases decay. Previous observations showed that strawberries harvested and packed under wet conditions can develop more decay. However, this mainly occurs during rainy periods and probably involves other preharvest factors. Ferreira et al. (2006) showed that hydrocooled strawberries had overall better quality than forced-air cooled, with significant differences in epidermal color, weight loss, incidence and severity of decay. Experiments were also conducted using water inoculated with *Botrytis cinerea*, in which hydrocooling with chlorinated water was effective in reducing decay (Ferreira et al.1996). Ferreira et al. (2009) found reduction in bruising sensitivity due to the fast cooling provided by the hydrocooling. Other researchers have employed hot water immersion treatments, which resulted in reduced decay incidence (Civello et al., 1997; Garcia et al, 1995; Vicente et al., 2002). The objective of this research was to determine the potential for hydrocooling strawberries compared with standard forced-air cooling in terms of the resulting fruit quality.

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Material and Methods

'Festival' strawberries (*Fragaria ×ananassa* cv. Festival) were harvested from a commercial farm in Plant City, FL, in Dec. 2010. The berries were harvested fully red, between 8 and 9 AM, field-packed into clamshells and brought to the Postharvest Horticulture Laboratory of the Horticultural Sciences Department, University of Florida, Gainesville.

The strawberries (28.12 g; SD ± 0.32) were removed from the clamshells, randomized, divided in two groups according to the treatments and treated around 6 h after the harvest. The initial pulp temperature was 22 °C and the treatments were: **a) Forced-air-cooling:** 15 fruit were placed into each clamshell (n = 16) and then arranged into two commercial corrugated flats. The two flats were placed lengthwise in a small, forced-air unit that was maintained in a 1 to 2 °C cold room. The pressure drop across the plenum was set to 0.5 inches water (125 mm) and the cooling time was 1 h. **b) Hydrocooling:** 80 fruit were placed into a small stainless-steel wire-mesh basket (15 × 15 × 15 cm) that allowed adequate water circulation. Chlorinated water (200 ppm free Cl-1, pH 6) was maintained between 1 and 2 °C using a refrigerated circulating water bath (Model 960, PolyScience, Niles, IL). Strawberry hydrocooling time was 12 min. After cooling 15 fruit were placed into clamshells and flats for storage. Cooling times to achieve 7/8 cooling by forced-air or hydrocooling were defined in previous experiments as the required time to cool strawberries from 22 °C to 4 °C in a 1 to 2 °C cooling medium.

Fruit from both treatments were stored for 7 d at 1 °C and then transferred to 5 °C for 7 d to simulate commercial handling. At the end of 7 and 14 d of storage, fruit were transferred to 20 °C for 48 h. Destructive analyses were conducted at 7, 14, 14+1, and 14+2 d. Nondestructive analyses were also conducted at 7+1 and 7+2 d. Four clamshells from each treatment were analyzed at each evaluation.

Nondestructive analyses

Weight gain/loss. Each clamshell was weighed before and after cooling and also throughout storage. Weight gain or loss was calculated based on initial weight and expressed as percentage of the initial weight. The water from the hydrocooled fruit was allowed to drain for 3 min before the initial weighing.

Color. External color was measured on opposite sides of five fruit from each clamshell (n = 20 berries per treatment, per analysis day) using a Minolta Chroma Meter model CR-400 (Konica Minolta Sensing Inc., Osaka, Japan) set for CIELAB color space and D65 light source. Color measurements were expressed in terms of Chroma (C*), Hue angle, and a* values.

Freshness. Individual fruit were rated according to the following 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; 1 = extremely poor: shriveled appearance. The results were expressed in average grade for each replication.

Calyx turgidity. Fruit were rated according to the following scale: 1= turgid; 2 = wilted; 3 = dried.

Decay. The number of fruit with any incidence of postharvest decay, especially visible mycelial growth, was recorded.

Bruising. The number of fruit with any postharvest mechanical damage was recorded.

Destructive analyses

Pulp firmness. Measurements were conducted on opposing sides of each fruit (n = 5 berries/clamshell; 20 fruit/treatment/analyses/d) using an Instron Universal Testing Instrument model 1132 (Instron Corp., Canton, MA), with a 5 kg load, crosshead speed of 10 cm·min^{-1} and a 4-mm-diameter convex probe. The maximum force necessary to penetrate 3 mm into the pulp was determined and results were expressed in Newtons (N).

After firmness measurements five fruit per replicate were frozen at –20 °C. Ten weeks later the samples were defrosted, homogenized, and then centrifuged at 17,600 g_n for 20 min at 5 °C. The supernatant was filtered through cheesecloth, and the filtrate (juice) was used to assess soluble solids content (SSC) and titratable acidity (TA).

Soluble solids content. SSC was determined by placing several drops of juice on the prism of a Mark II Abbe refractometer (Model 10480, Cambridge Instruments, Inc., Buffalo, NY) and reported as percent.

Titratable acidity and pH. The TA and pH were determined in the same equipment (Metrohm, Model 719 S Titrino, Herisau, Switzerland). Aliquots (6 g) of strawberry juice were diluted with 50 mL distilled water and pH was first determined before starting the titration with 0.1 N sodium hydroxide (NaOH) to an endpoint of pH 8.2, for the TA determination. The TA was expressed as percent citric acid.

Total anthocyanin. Total anthocyanins determination was conducted according to Nunes et al. (2006). Aliquots (2 g) of homogenated strawberry tissue were mixed with 18 mL of 0.5% HCl in methanol (v/v). Anthocyanin pigments were extracted by holding samples at 4 °C for 1 h in darkness. Samples were then filtered using single layer tissue (Kimwipe) to remove flocculate. Absorbance of the solution was measured at 520 nm. Pigment concentration was calculated using the following formula: Abs520 × dilution factor × (molecular weight (MW) of pelargonidin-3-glucoside (PGN)/molar extinction coefficient) where MW of PGN = 433.2 and the molar extinction coefficient = 29,080. Results were expressed as mg/100 g fresh weight of PGN.

Statistical analyses. The experiment was performed according to a completely randomized design. Data were analyzed by ANOVA and means were compared using the Tukey test at a significance level of 0.05.

Results and Discussion

Forced-air cooled fruit lost 1% of the initial weight immediately following cooling, while hydrocooled fruit gained at least 4% in weight (Fig. 1). Most of the gained weight in the hydrocooled fruit was due to the water on the surface of the fruit mainly in the calyx area. Only about 0.6% of the gained weight was due to the absorbed water. Fruit from both treatments lost weight during storage; however hydrocooled fruit were 2% to 3% heavier than air-cooled fruit at the end of 14 d at cold storage plus 2 d at room temperature (Fig. 1). The weight loss was different between treatments during all storage periods. Two percent to 3% in the weight loss can look insignificant for a few clamshells, but it can means tons of fruit weight loss on a commercial scale. The weight loss during the forced-air cooling ranges from 1% to 2%, depending on the characteristics of each product (Thompson et al., 2002), cooling time, cold room relative humidity and other factors. On the other hand, hydrocooling prevents water loss and may even add water to the commodity (Thompson et al., 2002). Ferreira et al. (2006) also reported that hydrocooled strawberries showed less weight loss than air cooled fruit and even gained weight when stored in either wrapped or unwrapped baskets.

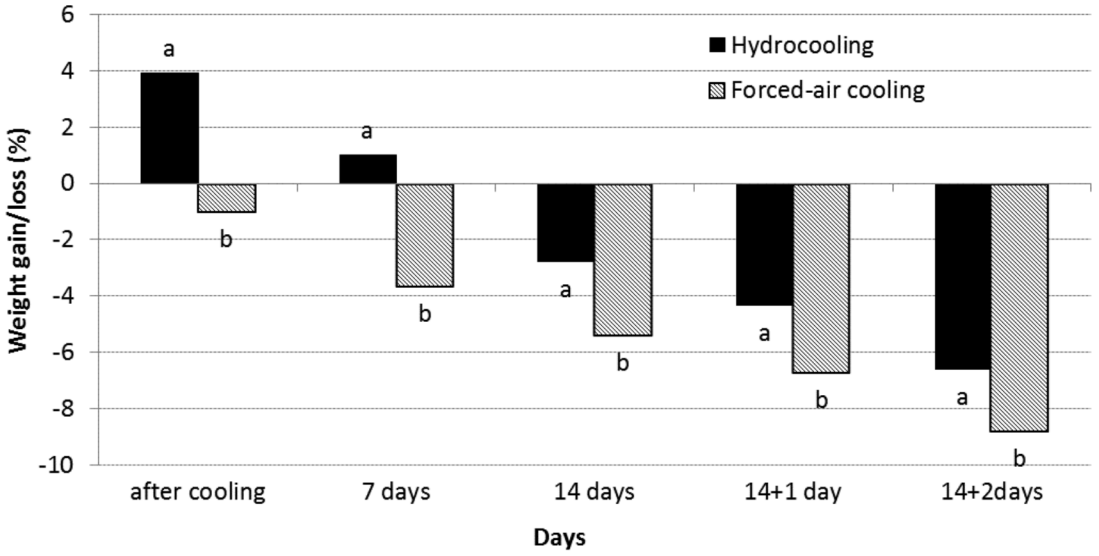

Fig. 1. Weight gain/loss (%) during cooling and storage of 'Festival' strawberry. Storage = 7 d at 1 °C + 7 d at 5 °C + 2 d at 20 °C. n = 4 to 20 clamshells with 15 fruit. Values with different letters within the same day are different according to the Tukey test ($P < 0.05$).

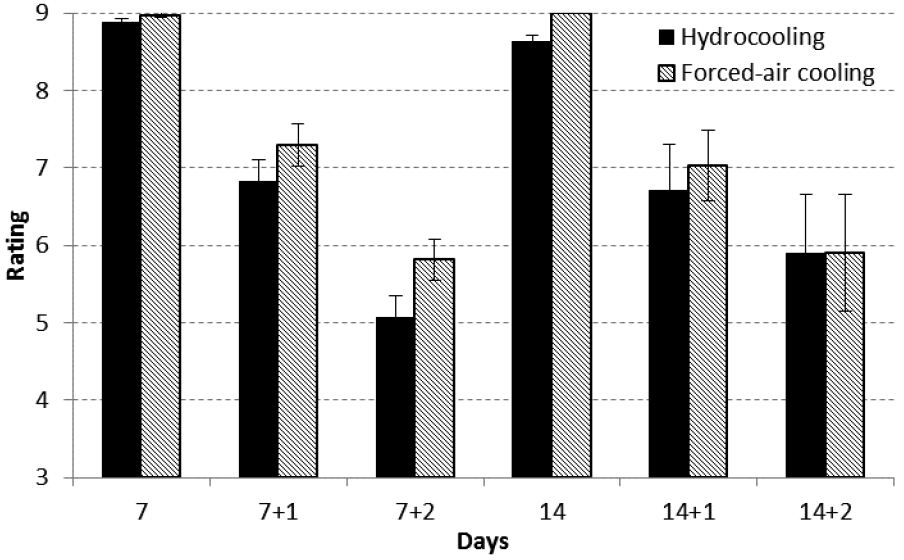

Fig. 2. Freshness of 'Festival' strawberry stored for 7 d at 1 °C + 7 d at 5 °C + 2 d at 20 °C after hydrocooling or forced-air cooling. Rating scale ranged from 9 = excellent (full fresh appearance, high sheen) to 1 = extremely poor (shriveled). Vertical bars represent ±SD. n = 4 replicates (15 fruit/replicate).

Strawberries appeared fresh during cold storage, but they lost fresh appearance following transfer to room temperature (Fig. 2). Freshness was rated as excellent (around 9 = full fresh appearance, high sheen) after 7 or 14 d in cold storage, but it decreased to 7 (good = still looks fresh, shiny) after one day at 20 °C, and 5 to 6 (5 = not fresh appearance, low sheen, limit of marketability) after 2 d at 20 °C. No statistical differences were observed between cooling treatments.

The decrease in the fresh appearance has been related to many factors such as water loss (Garcia et al., 1998), changes in the wax that covers the fruit, mechanical injuries (Prussia et al., 1993), and decay. In this work, freshness was related mostly to the gloss. At the end of the storage there were some dull and even shriveled fruit. It was expected that less water loss and faster cooling provided by the hydrocooling would be able to make the gloss last longer. However, this effect was not found. The lack of gloss maintenance in the hydrocooled fruit is probably due to two main reasons. The time between the harvest and the cooling was around 6 h. That was the time needed to bring the fruit from the field to the laboratory and to set up the experiment, but it is longer than the recommendation for commercial strawberry handling (Mitchell et al., 1996). Also, Nunes et al. (2005) found that promptly cooled strawberries had better quality than those cooled 5 h after harvesting. Another reason might be the conditions that the strawberries were exposed to simulating room temperature. Although the fruit were in the clamshell, those were

well vented and the air circulation in the Postharvest Horticulture Laboratory cold room is stronger than in typical commercial cold storage rooms.

Calyxes were rated accordingly to the effects of the treatments in terms of water loss. All calyxes were turgid after 7 d of cold storage and some of them were wilted after 14 d of cold storage. Additionally, most of them were wilted after 2 d at room temperature following 7 or 14 d under cold storage (Fig. 3). In terms of calix appearance, the storage condition seemed to be more important than the storage period in terms of calyx appearance. No cooling treatment effects were observed.

Hydrocooled strawberries were slightly firmer than fruit submitted to forced-air cooling, however there were no statistical differences due to cooling method or storage time (Table 1). Progressive flesh softening happens during the postharvest period of fruit as a result of the natural ripening process and is comprised of a complex process of many physiological mechanisms including cell turgor loss, enzymatic actions and degradation of cell wall compounds (Arifin, et all., 1998). It was expected that the faster cooling combined with the less water loss provided by the hydrocooling treatment would result in higher pulp firmness, though this effect was not observed.

SSC averaged 6.88% and no statistical difference was found due to the cooling treatment or the storage period (Table 1). TA decreased from the initial (0.87% of citric acid) to the end of storage (0.81%) (Table 1) in fruit of both treatments. In fact, changes in SSC, TA, sugars and organic acids are minimal during storage in non-climacteric fruit (Lavee and Nir ,1986). Chitarra and Chitarra (2005) also indicated that non-climacteric fruit shows little or no changes in sugar content during storage. According to Garcia et al. (1996) the decrease in sugar level was noted in the latter stages of senescence.

Total anthocyanin content increased gradually during the storage, from 17.24 to 22.67 mg PGN per 100 g of fresh pulp, irrespective of cooling treatment (Table 1). Gil et al. (1997) and Holcroft et al. (1999) also found a significant increase in strawberry anthocyanin content during storage. They worked with 'Selva' strawberry and observed that anthocyanin content increased less in fruit held in CO_2-enriched air. Anthocyanin biosynthesis can also be increased with higher pH up to 8.7 in strawberry cell suspension cultures (Zang and Furusaki, 1997).

The pH values increased slightly during the storage, but only in air-cooled fruit was it possible to observe a statistical difference. The initial pH value was 3.66; at the end of the storage it was 3.76 in hydrocooled fruit and 3.81 in the forced-air cooled fruit (Fig. 4). These results are according to the TA reduction as the decrease in the organic acid content leads to alkalization of the medium (Chitarra and Chitarra, 2005).

External color was measured from the seventh storage day until the end of the storage. Changes were observed during storage, but no differences were found between treatments. The C* and a* values increased from days 7 to 14 + 2 whereas hue angle did not change during that period (Fig. 5). In fact, changes happened following transfer to room temperature. Values of a* ranged from

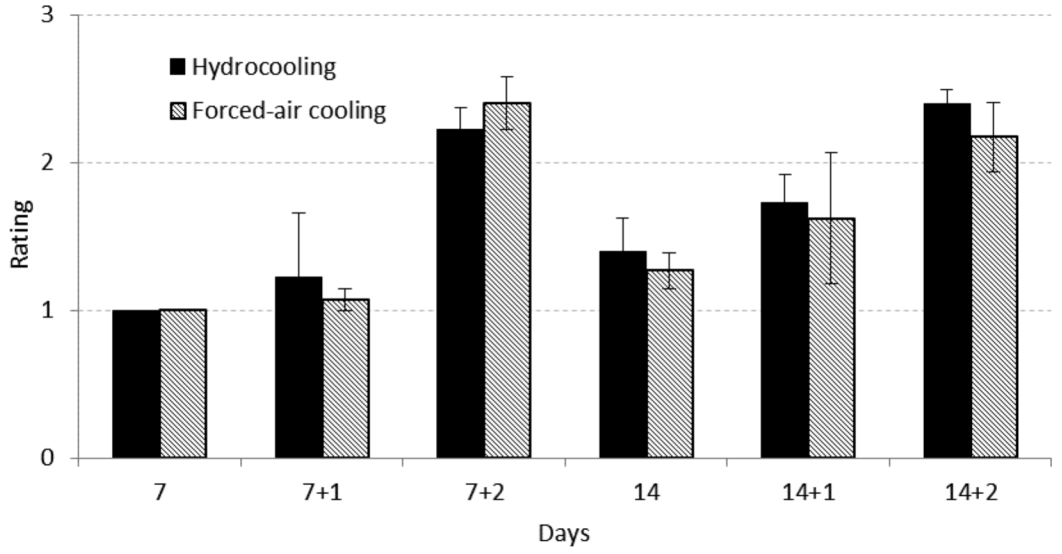

Fig. 3. Calyx appearance of 'Festival' strawberry stored for 7 d at 1 °C + 7 d at 5 °C + 2 d at 20 °C after hydrocooling or forced-air cooling. Grades according the following rating: 1 = turgid; 2 = wilted; 3 = dried. Vertical bars represent ±SD. n = 4 replicates (15 fruit/replicate).

Table 1. Pulp firmness, soluble solids content, titratable acidity and total anthocyanins of 'Festival' strawberry stored for 7 d at 1 °C + 7 d at 5 °C + 2 d at 20 °C after hydrocooling or forced-air cooling.

	Storage					
	0	7	14	14+1	14+2	LSD
Pulp firmness (N)	1.13 a[z]	1.25 a	1.37 a	1.42 a	1.34 a	0.39
Soluble solids content (%)	7.03 a	7.08 a	6.82 a	6.84 a	6.63 a	0.53
Titratable acidity (% of citric acid)	0.87 a	0.84 ab	0.83 ab	0.82 ab	0.81 b	0.05
Total anthocyanin (mg PGN 100 g^{-1})	17.24 b	18.58 ab	19.50 ab	20.84 ab	22.67 a	4.85

[z]Values followed by the same letter within the row are not different according to the Tukey test ($P < 0.05$).

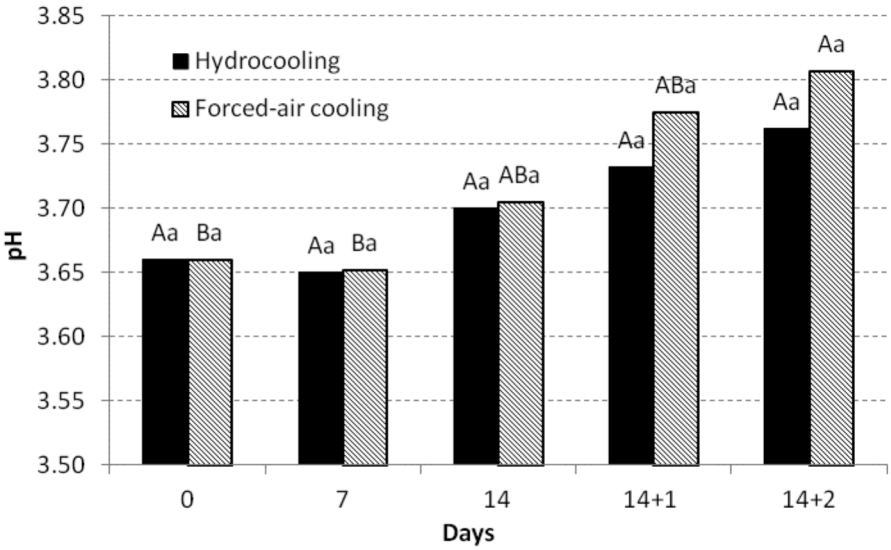

Fig. 4. pH of 'Festival' strawberry stored for 7 d at 1 °C + 7 d at 5 °C + 2 d at 20 °C after hydrocooling or forced-air cooling. Values with same capital letter in the same treatment or same small letter on the same day are not different according to the Tukey test ($P < 0.05$).

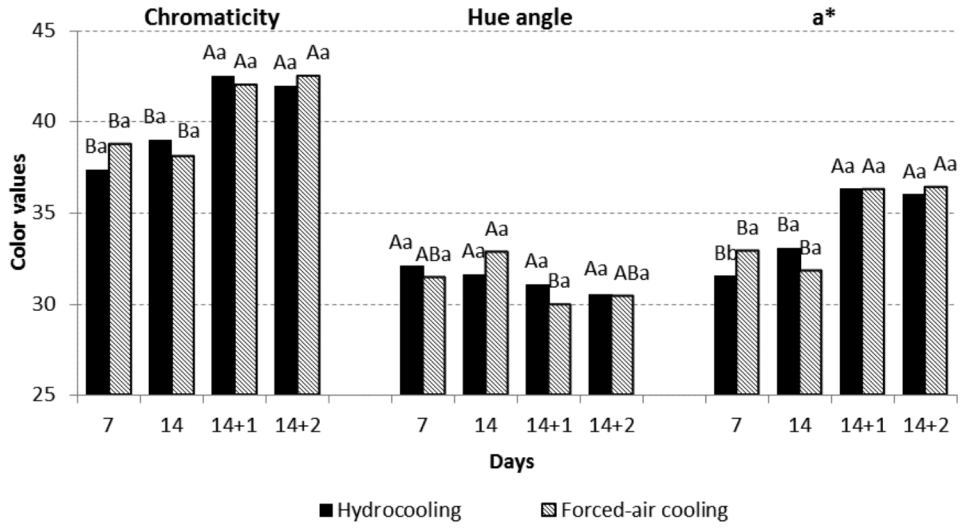

Fig. 5. Chromaticity (C*), hue angle (h) and a* values of 'Festival' strawberry stored for 7 d at 1 °C + 7 d at 5 °C + 2 d at 20 °C after hydrocooling or forced-air cooling. (n = 20 fruit, 2 readings/fruit). Values with same capital letter in the same treatment or same small letter on the same day are not different according to the Tukey test ($P < 0.05$).

32.33 during cold storage to 36.26 at room temperature, where higher a* values indicate more red pigments in the measured surface. These results correlated positively with the total anthocyanins content, which also increased during storage (Table 1). Indeed, strawberry red color is a result of the anthocyanin presence in the fruit, especially in the epidermis and achene (Aaby et al., 2005). Other authors also linked the anthocyanin content increase with the red color increase (Gil et al., 1997; Holcroft et al., 1999).The increase in C* values confirmed that strawberries were more intensely red at the end of the storage than at day 7 of storage, as higher C* values indicate more vivid colors.

No decay was found on the fruit after 14 d under cold storage plus 2 d at room temperature, even though strawberries are highly sensitive to decay. Probably, this unexpected absence of decay was related to the season which the fruit were collected, since fruit from the early season are less susceptible to decay than those from the middle or end of the season. These fruit were obtained from one of the first harvests of a healthy field.

Bruises were more evident on fruit from hydrocooling than forced-air cooling. These results are probably a consequence of the additional handling used in the hydrocooling process, since the fruit were cooled in baskets before being put back into clamshells. This additional handling was necessary because the strawberries were field packed into clamshells before being transported to the laboratory. In subsequent experiments, strawberries were hydrocooled inside the clamshells with no additional handling (data not shown). The future studies of this project, cooling methods will be compared side-by-side in a semi-commercial facility.

This experiment showed that hydrocooling can be an alternative to forced-air-cooling of strawberries. The former method

cooled much faster, which can be relevant in terms of fruit flow (throughput) in the packinghouse and energy savings.

Hydrocooling did not affect the fruit quality during cold storage in terms of physical and chemical analyses, freshness or decay. Use of this method resulted in fruit that were 2% to 3% heavier than those that were forced-air-cooled by the end of the storage time.

The free water on the fruit surfaces and inside of the clamshell container did not induce any promotion of storage decay. The greater amount of bruising in the hydrocooled fruit was a consequence of additional handling during the experiment.

Further experiments should be done to simulate commercial handling and to determine the effect of the treatments with regard to sanitization, bruising, technical feasibility, and costs of investment and operation.

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