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Environmental Conditions Encountered during Distribution from the Field to the Store Affect the Quality of Strawberry ('Albion')

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Strawberries are one of the most appreciated fruits due to their delicate flavor. However, the fruit is fragile and deteriorates rapidly if handled under adverse conditions. Long transit times from the field to the retail store and poor handling conditions often result in very short shelf life and poor overall quality. In order to understand the impact of transit conditions on the quality of 'Albion' strawberry, two shipments of strawberries were monitored from the field in California, thru the distribution center, and finally to a retail store in Georgia. Strawberries were selected and evaluated at the field for appearance, weight, incidence of bruising and decay, and soluble solids content. Temperature and humidity data loggers were placed inside clamshells containing the selected fruit to monitor the environmental conditions during transit. Quality of the selected fruit was then evaluated after pre-cooling, upon arrival to the distribution center, and at the store. The transit times varied between 7 and 9 d, with temperatures ranging from 0 to 30 °C and 34 to 87% relative humidity. Overall, results from this study showed unacceptable strawberry quality due to poor appearance upon arrival to the distribution center. Weight loss, incidence of bruise and decay increased during transit while appearance and soluble solids content decreased. The major causes of fruit rejection at the store level were decay and bruising, which affected 26.8% and 75.3% of the fruit, respectively. Long transit times and abuse temperatures shortened the shelf life of the strawberries and contributed to poor fruit quality.

Quality of strawberries is based primarily on color, texture and fruit flavor. For best eating quality, strawberries should be harvested at or near the full ripe stage as immature fruit have poor eating quality (i.e., low sugar and vitamin C contents and poor flavor) (Kader, 1991; Nunes et al., 2006a). However, firm ripe strawberries are fragile and thus very susceptible to bruising and decay. The quality of strawberries available at the retail store depends not only on the initial quality at harvest but also on the way the fruit was handled from the field to the store, with the length of time and environmental conditions (i.e., temperature and humidity) during handling and distribution having a significant impact on its quality and shelf life.

Strawberries may experience a long handling process from harvest to the store and thus there are many points in which the fruit can be exposed to abuse temperatures. A typical strawberry handling process involves: harvesting, packing, palletizing, transporting from the field to the cooling facilities, pre-cooling and storing under refrigerated conditions, shipping to the distribution center (DC) and transportation from the DC to the store, and finally displaying in the store until purchased by the consumer. Delays before pre-cooling, inadequate pre-cooling and abuse/fluctuating temperatures during storage and distribution simultaneously with long transit times can significantly shorten the shelf life of strawberry. For example, delaying cooling has been shown to decrease the quality of the strawberry fruit with increased losses of AA, soluble solids, fructose, glucose, and sucrose (Nunes et al., 1995b). When the temperature of the fruit is raised from 0 to 10 °C, the rate of deterioration increased by 2- to 4-fold, and when strawberries were held at 29.4 °C for different periods after harvest before pre-cooling a very rapid reduction in the amount of marketable fruit was observed (Mitchell et al., 1996). Therefore, in order to reduce decay and loss of quality during storage, strawberries should be pre-cooled immediately after harvest or not more than 2 or 3 h after harvest (Mitchell et al., 1996; Nunes et al., 1995b, 2005). In addition, compared to a 6-h delayed cooling, prompt pre-cooling reduced incidence of decay (*Botrytis cinerea* and *Rhizopus stolonifer*) by 25% and severity by about 24% (Nunes et al., 2005).

Fluctuating temperatures commonly encountered during distribution may also be detrimental to strawberry quality. For example, Nunes and Emond (1999) showed that strawberries stored in fluctuating temperatures had higher weight loss and pH, and lower firmness and glucose content than those stored at constant temperature. In addition, temperature fluctuations can result in water condensation on commodity surfaces, potentially causing increases in the development of decay by fungal and bacterial pathogens. In summary, since strawberries are not sensitive to low temperatures, they should be pre-cooled and maintained at a constant temperature around 0 °C in order to retain maximum acceptable quality and shelf life. Storage temperatures higher than 0 °C greatly reduce postharvest life and even at the optimum storage temperature, the postharvest life of strawberries can be as short as 7 to 8 d (Ayala-Zavala et al., 2004; Mitcham, 2004; Nunes, 2008).

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Poor temperature management and long transit times inevitably occur in commercial handling and reduce the quality and maximum potential shelf life of strawberries. Few studies have been published on the effects of environmental conditions throughout the entire postharvest handling process, from the field to the store, on the quality of fruit and vegetables (Beaudry et al., 1998; Dea et al., 2008; Laurin et al. 2003; Nunes et al., 2003, 2006b). The majority of these studies, while based on real environmental conditions encountered during produce handling and distribution, were performed under simulated laboratory conditions and, information is still lacking on real commercial operations and transit times as well as temperatures and humidity registered from the field to the retail store and their impact on produce quality. Thus, this study was designed to evaluate a real strawberry supply chain that comprises the time the fruit is harvested and delivered to the retail store as well as the impact on the quality of the fruit.

Materials and Methods

Fruit selection and instrumentation

'Albion' strawberries were harvested twice from the same commercial field in California on Sept. and Oct. 2008. Strawberries were commercially hand-picked, placed inside clear plastic clamshells, and then inside cardboard flats (each flat accommodates 8 clamshells containing 454 g of fruit each; approximately 20 to 22 fruit per clamshell). The flats were identified with bright orange tags and then assembled to form a pallet which contained 18 rows of 6 flats per row. For each field trial/ harvest two pallets of strawberries were monitored. From each pallet, 9 flats of strawberries were identified and from the 9 flats, 27 clamshells of strawberries (3 clamshells per flat) were used for non-destructive quality evaluations. The remaining 45 clamshells of strawberries (5 clamshells per flat) were used for destructive quality evaluation, and for temperature and humidity monitoring. A total of 144 clamshells from the two pallets (54 clamshells for non-destructive and 90 for destructive quality evaluations) were used for each field trial.

After the fruit were selected and quality evaluated, a total of 18 temperature and humidity battery-powered data loggers (Hobo® U10 Temp/RH data logger, Onset Computer Corp., Pocasset, MA) were placed inside the clamshells for temperature and humidity monitoring (9 data loggers per pallet). The data loggers were programmed to record temperature and RH data every 2 s throughout the study, from the field to the store. The pallets were then assembled with the flats containing the selected fruit being placed in rows 14, 15, and 16 (3 flats per row). The pallets were then removed from the field and brought to the cooling facilities. The trip from the field to the warehouse was approximately 30 min, after which the fruit were commercially forced-air cooled.

Handling operations

After pre-cooling, the strawberries were treated using a TECTROL® system and then stored in a cold room at the grower, set at approximately 1 °C, before being loaded into the distribution truck. From the 18 flats of strawberries initially selected, 6 flats (3 flats from each pallet) were stored at the grower under continuous cold storage (steady) throughout the whole distribution period. The remaining 12 flats were kept in the original pallets, loaded inside a refrigerated truck (front and middle of the truck) and shipped to a distribution center (DC) in Georgia. Six of these flats were then collected from the DC for quality evaluation while the remaining six flats were shipped to a store in Georgia and were collected upon arrival for quality evaluation.

Quality evaluation

Because complex analytical techniques are difficult to use when working in open field, simple procedures were used to evaluate the quality of strawberry. Thus, subjective quality evaluations such as appearance of the fruit, incidence of bruising and decay, and non-subjective evaluations such as weight loss and soluble solids content (SSC) were used as basic quality evaluation procedures. Quality evaluations of all selected fruit for testing were performed initially in the field, just after the fruit were harvested, and after pre-cooling. Quality of fruit designated for transportation was evaluated upon arrival at the DC and upon arrival at the store. For non-destructive quality evaluations (weight, appearance, bruising and decay) the same fruit were used throughout the study (a total of 54 clamshells with an average of 20 fruit per clamshell). For destructive analysis (SSC) the remaining clamshells in the cardboard flat were used (90 clamshells). Note that, for the second harvest, due to limitations at the grower, quality of the fruit kept under steady conditions was evaluated right after harvest (initial) and after pre-cooling only.

Visual quality

Visual quality of strawberries was evaluated always by the same trained person. Overall appearance of the fruit such as freshness and color was determined subjectively using a 1 to 5 visual rating scale where, 5 = excellent quality, fresh from the field and 1 = very poor quality, not acceptable for sale or consumption (Table 1). A score of 3 was considered the limit of acceptability before strawberry becomes unmarketable.

Table 1. Visual quality rating and descriptors for strawberry.

Score	Description
5.0	90% red; bright, glossy; calyx stiff, green; no shriveling or bruising; fruit appears very fresh (excellent)
4.5	95% red; slightly less bright and glossy; calyx green but slightly less stiff; no shriveling (very good)
4.0	Full red; less bright and less glossy; calyx green but slightly less stiff; minor signs of shriveling (good)
3.5	Full red; less bright and less glossy; calyx less fresh; signs of dryness may be noticeable (good to acceptable)
3.0[z]	Full to dark red; slight loss of brightness and gloss; calyx may appear dry and wilted; isolated areas of dryness; soft spots (acceptable)
2.5	Full dark red; moderate loss of gloss; calyx appears wilted, dry; moderate shriveling, dryness; soft spots (acceptable to poor)
2.0	Very dark red; dull, not glossy; overripe, dry appearance; fruit is soft; calyx dry and yellowish or greenish-brown (poor)
1.5	Very dark, dull purplish color; fruit is soft, overripe and dry; some fruits may be leaky; calyx dry and wilted (poor to very poor)
1.0	Very dark brownish or purplish-red color; very dull, soft, dry or leaky, calyx is yellowish or brownish and dry (very poor)

[z]Rating of 3 is considered the maximum acceptable before strawberry becomes unacceptable for sale.

Incidence of bruising and decay

Incidence of bruising and decay was recorded by counting the number of strawberries in each clamshell with the presence of any (i.e., small or large) noticeable sign of decay or bruising. The percentage of fruit showing bruising or decay was then calculated based on the total number of fruit in each clamshell.

Weight loss

Weight loss of each replicate of 20 strawberries per clamshell was calculated from the initial weight of strawberries and after each evaluation step using a precision balance with an accuracy of ±0.1 g (Mettler Toledo Model PL 1501-S, Mettler Toledo GmbH Laboratory and Weighing Technologies, Switzerland).

Soluble solids content (SSC)

Ten strawberries per evaluation time per treatment were hand squeezed inside a plastic bag and the juice extracted by filtering through cheesecloth. The SSC was then determined by placing two drops of juice on the prism of a handlheld refractometer (r^2 mini handheld refractometer, Reichert Analytical Instruments, Depew, NY). SSC was expressed in terms of fresh and dry weight in order to show the differences between treatments that might be obscured by differences in water content. The following formula was used for water loss corrections: [(SSC on a fresh weight basis ´ 100 g) / (9.6 g (strawberry average dry weight) + weight loss during storage (g))] (Proulx et al. 2010). Strawberry average dry weight was calculated based on published values for strawberry (Nunes et al., 1995a; USDA, 2010).

Statistical analysis

There were a total of two pallets per field trial/harvest containing 9 cardboard flats of strawberries each (total of 18 flats of strawberries per field trial/harvest). Each flat had 8 clamshells and each clamshell contained on average 20 fruit (total of 144 clamshells). Two temperature treatments (steady and fluctuating) were applied to the 18 flats of strawberries: 6 flats were used for the steady temperature treatment (left at the grower); 12 flats were used for the fluctuating temperature treatment (6 shipped to the DC and 6 shipped to the store). Quality evaluations were performed initially (right after harvest), after pre-cooling, at the DC and at the store). Field trials were repeated twice (first and second harvest). The analysis of variance was performed using the Statistical Analysis System 9.1 computer package (SAS Institute, Inc., Cary, NC). Data from the two field trials/harvests were analyzed separately as initial statistical analysis showed significant differences between harvests for most of the factors evaluated. However, no significant differences were obtained for the two pallets therefore data from the two different pallets was combined and analyzed simultaneously. Significant differences among the treatments (steady and shipped) were detected using the least significant difference (LSD) test at the 5% level of significance.

Results and Discussion

Handling operations

Strawberries from the first harvest were removed from the field within 5 h of harvest and pre-cooled for 2 h whereas fruit from the second harvest were left in the field for 6 h and upon arrival at the cooling facilities pre-cooled for 1 h (Table 2). After pre-cooling, strawberries were kept in a refrigerated room during 41 or 24 h for the first and second harvest, respectively, and then loaded into refrigerated trucks and shipped to the DC in Georgia. The transit times from the grower in California to the DC in Georgia were 115 and 106 h for the first and second harvest, respectively. Upon arrival at the DC, strawberries were stored in a refrigerated room for 41 and 13 h for the first and second harvest, respectively. Later, the strawberries were shipped to a store in Georgia with transit times of 4 to 17 h for the first and second harvest, respectively. Upon arrival at the store, they were kept in consumer displays for 4 and 5 h for fruit from the first and second harvest, respectively (Table 2).

The time it took the fruit to travel from the field to the store was 212 h (8.8 d) and 172 h (7.2 d) for the first and second harvests, respectively. Overall, the handling time from the field to the store was 1.6 d longer for the first harvest compared to the second harvest. Strawberries from the first harvest spent longer times at the grower cold room, shipping to the DC, and storage at the DC than fruit from the second harvest, whereas fruit from the second harvest spent longer time in transit from the DC to the store than the first harvest (Table 2). The time difference between the two field trials/harvests, as well as the long transit times from the field to the store, were mostly due to logistic issues related to grower and retailer protocols for shipping, load acceptance, unloading and store delivery.

Overall, the time it took the fruit to arrive from the field to the

Table 2. Time and average temperature and relative humidity (RH) measured during shipping and distribution of strawberry (cv. Albion) from the field to the store.

	First harvest			Second harvest		
	Time (hours elapsed)	Temp (°C)	RH (%)	Time (hours elapsed)	Temp (°C)	RH (%)
Harvest[z]	0	---	---	0	---	---
Harvest to pre-cool	5	24.9	51.6	6	29.6	33.8
Pre-cooling[y]	2 (7)	0.8	71.7	1 (7)	3.1	67.9
Cold room (grower)	41 (48)	1.1	77.7	24 (31)	0.3	80.9
Shipping to DC (truck)[x]	115 (163)	3.0	83.2	106 (137)	2.0	84.9
Storage DC	41 (204)	1.0	84.9	13 (150)	0.4	77.6
Transport from DC to store[w]	4 (208)	4.3	87.2	17 (167)	1.8	79.2
Store	4 (212)	3.7	82.6	5 (172)	4.5	85.4
Total time	212 (8.8 d)			172 (7.2 d)		

[z]Initial quality evaluation at harvest (0 h = 0 d)
[y]Quality evaluated after pre-cooling (7 h = 0.3 d)
[x]Quality evaluated upon arrival to the DC (first harvest: 163 h, 6.8 d; second harvest: 137 h, 5.7 d)
[w]Quality evaluated upon arrival to the store (first harvest: 212 h, 8.8 d; second harvest: 172 h, 7.2 d)

store was too long for both harvests considering that the postharvest life of strawberry can be as short as 7 to 8 d, even if stored at optimum temperature (0 °C) (Mitcham, 2004; Nunes, 2008). In addition, long delays before pre-cooling (5 and 6 h for the first and second harvests, respectively) might have also shortened the shelf life and resulted in a poor quality fruit upon arrival at the retail level. Several studies have shown that the longer the time before pre-cooling the shorter the shelf life of strawberries. Therefore, in order to reduce decay and loss of quality, strawberries should be pre-cooled immediately after harvest or not more than 2 to 3 h after harvest (Nunes et al., 1995a, 1995b; Mitchell et al., 1996; Nunes et al., 2005).

Temperature and relative humidity (RH) during handling

Strawberries from both harvests were handled under a fluctuating temperature and RH regime (Table 2). Average field temperatures were higher and RH lower during the second harvest (29.6 °C; 33.8% RH) compared to the first harvest (24.9 °C; 51.6% RH). During pre-cooling, average temperatures were lower and RH higher for fruit from the first harvest compared to the second harvest. During storage at the grower, DC and store and during shipping, differences in the average temperature between the first and second harvest were smaller and ranged from approximately1.0 to 2.0 °C. During storage and shipping, average humidity levels also varied with a difference between harvests ranging from approximately 2.0% to 8.0%. For the first harvest, the highest temperature was measured during transport from the DC to the store and at the store and the highest RH was measured during transport from the DC to the store. For the second harvest, the highest temperature and RH was measured at the store. Strawberries that were left at the grower facilities under steady conditions were kept at 0.3 to 1.1 °C and 77.7 to 80.9% RH for the entire length of the shipping and handling.

As mentioned above, exposure of strawberries for extended periods of time (i.e., more than 3 h) at high field temperatures such as measured in this study (24.9 and 29.6 °C for the first and second harvest, respectively) may have shorten the shelf life of the fruit. Besides the delays in pre-cooling, strawberries were afterward handled under fluctuating temperatures that ranged from approximately 1.0 to 4.0 °C or from 0 to 5.0 °C for the first and second harvest, respectively. Fluctuating temperatures during handling may cause moisture condensation on the fruit, which favors the growth of surface mold and development of decay (Boyette et al., 1989; Hardenburg et al., 1986). Further, exposure of strawberries to fluctuating temperatures may result in increased loss of quality. For example, in a previous study Nunes et al. (2003) reported that strawberries exposed to fluctuating temperatures were softer, had higher weight loss and lower vitamin C contents compared to fruit handled under constant temperatures.

Weight loss

For both harvests, strawberry weight loss increased during handling from the field to the store and also in fruit that was kept at the grower under steady conditions (Fig. 1). However, strawberries kept under steady conditions at the grower had more weight loss than shipped fruit, most likely due to a combination of several factors such as, the high air circulation inside the cold room; the low RH of the room and also due to the fact that shipped pallets were, after pre-cooling, entirely covered with a plastic wrap (Tectrol System®) which might have prevented from water loss, whereas strawberry flats from the steady treatment were not wrapped. After pre-cooling, strawberries from the first and second harvest lost approximately 0.6% and 2.4% of their initial weight, respectively. Upon arrival at the store strawberry weight loss was approximately 2.0% and 4.0% for fruit from the first and second harvest, respectively. Overall, shipped strawberries from the second harvest had higher weight loss compared to those from the first harvest probably due to the lower RH levels measured for the second harvest, mostly during delays before cooling, during pre-cooling, storage at DC and transport from DC to store (Table 2).

During handling from the field to the store 'Albion' strawberries lost 3.0% or 5.0% of its initial weight, for the first and second harvest, respectively. According to Robinson et al. (1975) a 6.0% weight loss is the maximum acceptable for strawberry marketability, thus weight loss values obtained in this study would not

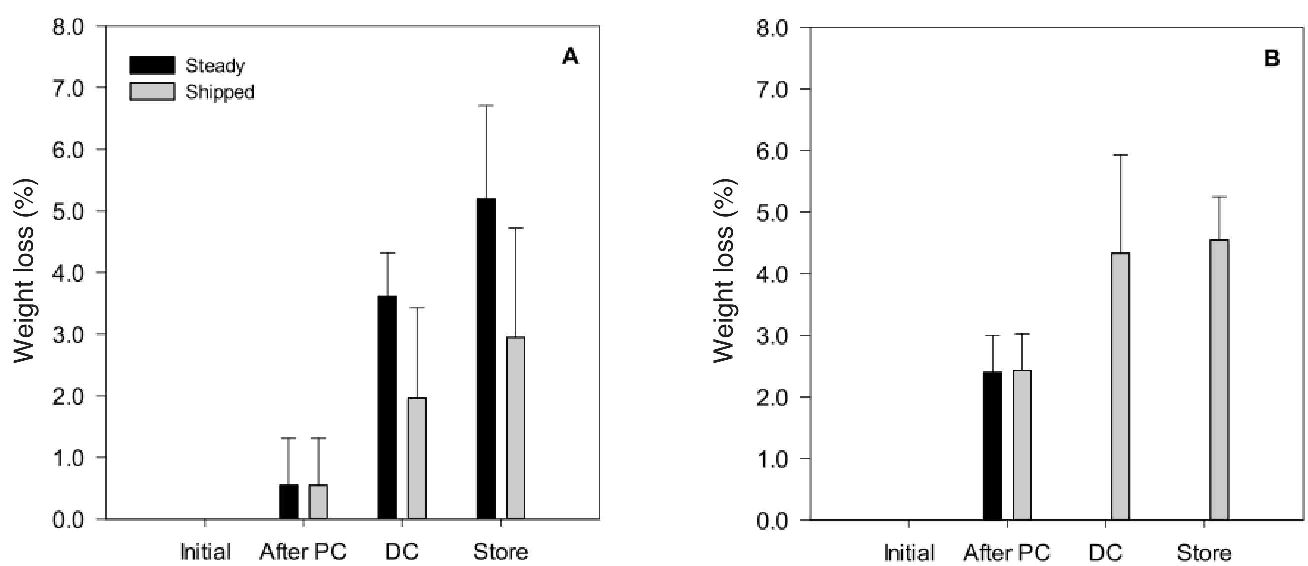

Fig. 1. Weight loss of 'Albion' strawberries during shipping and distribution from the field to the store: (**A**) first harvest; (**B**) second harvest; PC = pre-cooling; DC = distribution center.

be considered unacceptable. However, in a more recent study, a weight loss of 2.5% to 3.0% in 'Seascape' strawberries resulted in softening of the flesh, darkening of the color, over ripeness, shriveling and dryness of the calyx and skin (Nunes and Emond, 2007). Weight loss is highly correlated to loss of water and tends to increase as temperature increases and RH decreases. For example, when strawberries were dipped in calcium chloride coating solutions weight loss was reduced when coating decreased the water permeability (García et al., 1996).

Visual quality

Appearance of the fruit deteriorated significantly during shipping or under steady temperature conditions (Fig. 2). When evaluated at the DC level, appearance of shipped strawberries was already past the maximum acceptable levels (rating of 3). Shipped fruit from both harvests appeared dark red, overripe and the calyxes were dry and wilted when evaluated upon arrival at the DC or store. Strawberries maintained under steady conditions had significant different ratings than shipped fruit. Steady fruit had a slightly better quality appearance (higher scores) than shipped fruit with less wilting and brighter color at the time shipped fruit arrived at the DC but appearance also deteriorated at the time of arrival at the store.

Delayed cooling combined with high fluctuating temperatures during shipping have a significant impact on strawberry appearance, composition and eating quality. Strawberries exposed to adverse conditions become softer, shriveled, darker in color, and with lower levels of SSC, AA, and sugar when compared to strawberries that were promptly pre-cooled and kept at optimum constant temperatures (Nunes, 2008; Nunes et al., 1995a).

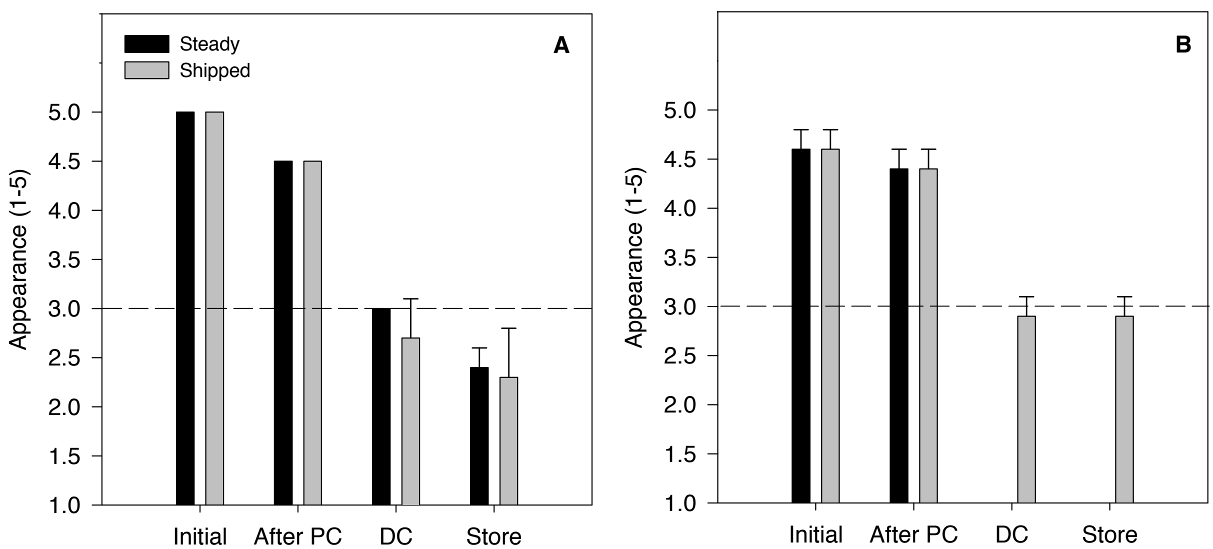

Fig. 2. Appearance of 'Albion' strawberries during shipping and distribution from the field to the store. Dotted line (rating of 3) represents the maximum acceptable quality before the fruit becomes unsalable. A = first harvest; B = second harvest; PC = pre-cooling; DC = distribution center.

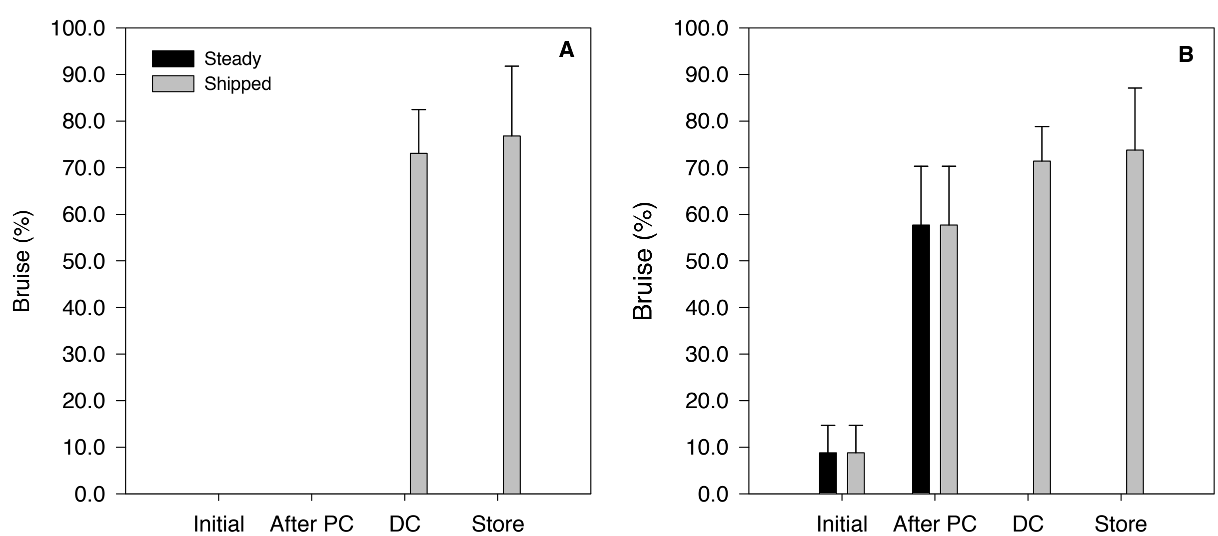

Fig. 3. Incidence of bruising in 'Albion' strawberries during distribution from the field to the store. A = first harvest; B = second harvest; PC = pre-cooling; DC = distribution center.

Incidence of bruising and decay

Strawberries from the second harvest showed a high percentage of bruising at harvest (8.8%) while fruit from the first harvest had no bruises (Fig. 3). For both harvests, incidence of bruising increased significantly in shipped strawberries upon arrival at the DC and store. Upon arrival at the DC, 73.1% and 71.4% of the fruit from the first and second harvest, respectively, were bruised, and at the store the incidence of bruising increased to 76.8% and 73.8% for the first and second harvest, respectively.

Decay increased in strawberries during shipping but was much lower or nonexistent in fruit kept under steady conditions at the grower (Fig. 4). Upon arrival at the DC, shipped fruit from the first harvest showed a 7.0% incidence of decay, whereas decay affected almost 20.0% of the fruit from the second harvest shipped to the DC. At the store, decay significantly increased, affecting 26.0% and 27.6% of the fruit from the first and second harvest, respectively.

During truck transportation, strawberry fruit most likely experienced shock and vibration, with fruit rubbing against each other and against the walls of the clamshells. Mechanical injuries such as punctures, bruises, or cuts tend to weaken the fruit structural integrity leading subsequently to infection of fungal growth. In a previous study, mechanically damaged fruit exposed to high fluctuating temperatures also tended to develop more decay during subsequent storage than intact fruit (Nunes et al., 2003, 2005).

Soluble solids content (SSC)

The water loss that occurred during handling of strawberry fruit tended to mask real losses of SSC expressed on a fresh weight basis; in some cases seeming to show no difference, or even greater retention of the SSC compared to the strawberry fruit at the time of harvest (Fig. 5). Although it might be argued that the SSC values expressed on a fresh weight basis represent the actual concentrations that would be experienced by consumers, the data is also expressed on a dry weight basis in order to illustrate the actual losses that occurred in the SSC irrespective of the concentrating effect imposed by water loss. Therefore, compared to initial values at harvest SSC content of strawberry on a dry base weight decreased in shipped and steady fruit (Fig. 5). Overall, the initial SSC of strawberry at the time of harvest was reduced by approximately 23.0% when the fruit arrived at the store.

Decrease in SSC of strawberries had been previously reported when strawberries were handled under high temperatures. Reduction in SSC in strawberries exposed to abuse temperatures is mostly due to the depletion of the sugars reserves that results from an increase in fruit respiration metabolism, which involves the consumption of simple sugars (Ayala-Zavala et al., 2004). Delayed pre-cooling also causes increased losses in SSC compared to fruit that were promptly pre-cooled (Nunes et al., 1995b).

Conclusions

Due to usual logistic variables, comparable postharvest treatments and shipping conditions are often difficult to replicate when conducting real life experiments. Besides, because of the high cost associated with this type of experimental procedures (i.e., travel, lodging, labor), many repetitions are not always possible. Nonetheless, results from this study showed that long holding times at the grower before shipping strawberries across the country are a reality, and most likely combined with other inadequate handling conditions contribute to the poor appearance of the fruit often seen at the retail level. Exposure to temperature and RH profiles encountered during real strawberry handling, from field to the store, resulted in deterioration of fruit quality due to increased weight loss and incidence of bruising and decay, and decreased fresh appearance and SSC. This study shows that delays before cooling combined with long transit times and fluctuating temperatures encountered during handling of strawberry fruit from the field to the store contributed to poor quality and to rejection of loads of strawberry at the DC and store level. Finally, during handling of strawberry fruit from the field to the store, proper temperature management, fruit ripeness stage, and initial quality as well as weather conditions at the time of harvest, should all be taken into consideration, as abuse and/or fluctuating temperatures that are typically encountered during handling and shipping operations may result in important losses at the retail or in consumers' homes.

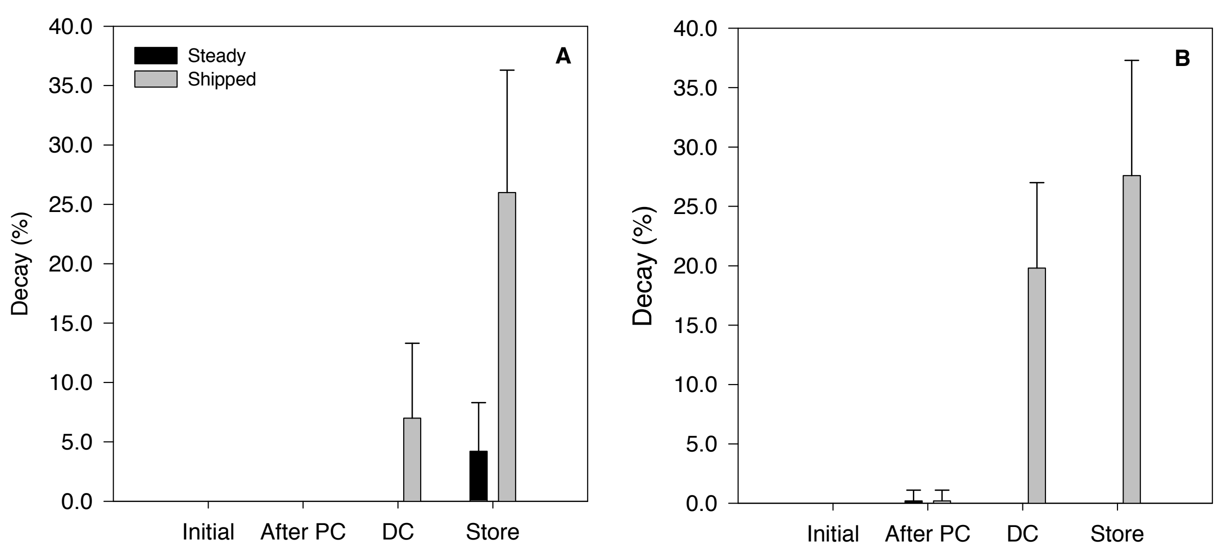

Fig. 4. Incidence of decay in 'Albion' strawberries during distribution from the field to the store. A = first harvest; B = second harvest; PC = pre-cooling; DC = distribution center.

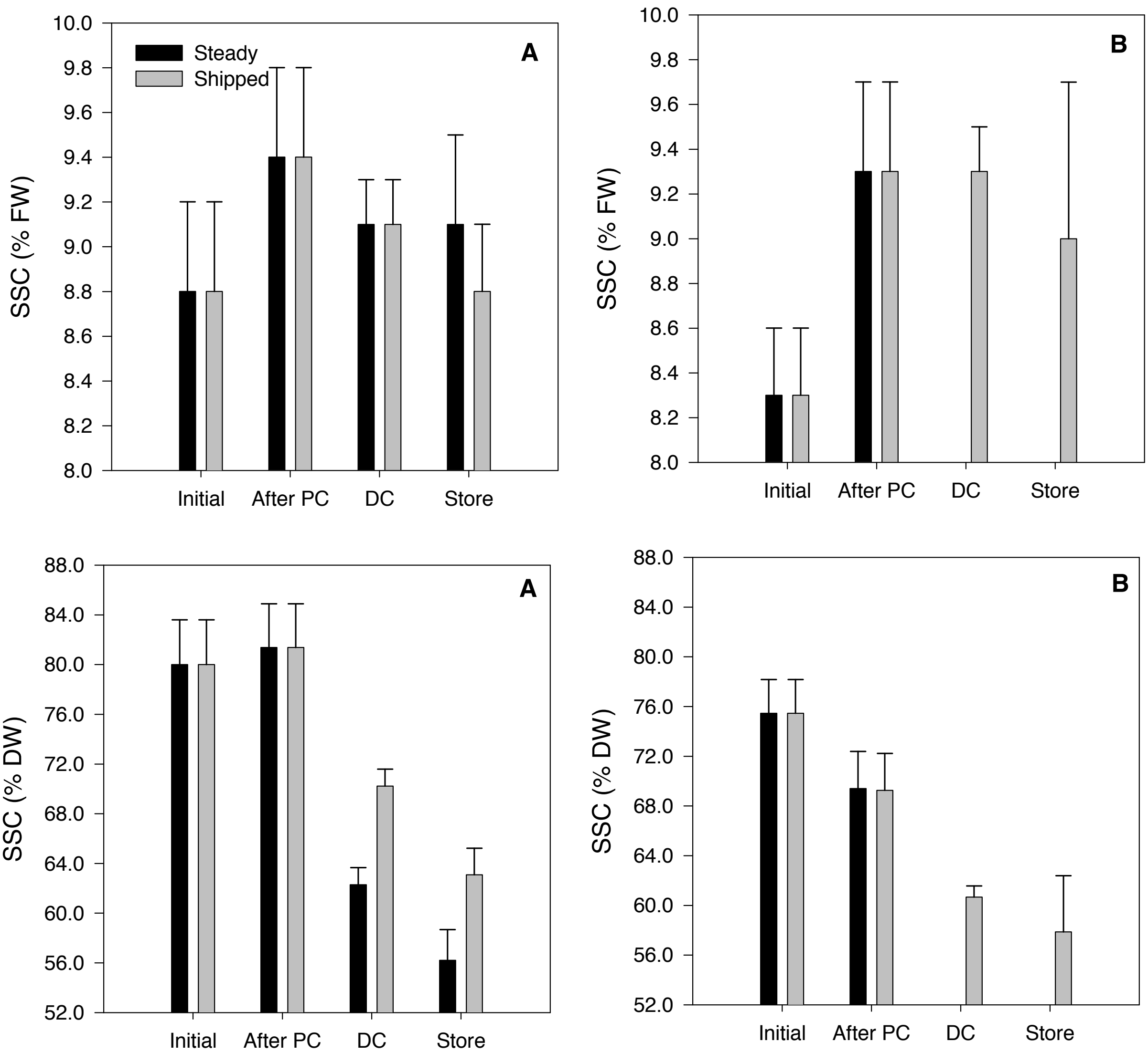

Fig. 5. Soluble solids content (SSC) of 'Albion' strawberries measured during distribution from the field to the store and expressed in terms of fresh (FW) and dry weight (DW). A = first harvest; B = second harvest; PC = pre-cooling; DC = distribution center.

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