Controlled Delayed Cooling Extends Peach Market Life

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SUMMARY. **A commercial controlled delayed cooling or preconditioning treatment was developed to extend peach (*Prunus persica*) market life of the most popular California peach cultivars. A 24 to 48 h cooling delay at 68 °F (20.0 °C) was the most effective treatment for extending market life of internal breakdown susceptible peaches without causing fruit deterioration. This treatment increased minimum market life by up to 2 weeks in the cultivars tested. Weight loss and softening occurred during the controlled delayed cooling treatments, but did not reduce fruit quality. Detailed monitoring of these fruit quality changes during the delayed cooling period and proper use of fungicides is highly recommended for success in this new fruit delivery system. Rapid cooling after preconditioning is important to stop further fruit deterioration such as flesh softening, senescence, decay and weight loss. Controlled delayed cooling can also be used to pre-ripen susceptible and nonsusceptible peaches to deliver a ready-to-buy product to the consumer.**

Some of the most frequent complaints by peach consumers and store produce managers are the presence of off-flavors, flesh mealiness (dry fruit or woolliness), flesh browning, and lack of ripening (Bruhn et al., 1991). These symptoms are a consequence of internal breakdown (IB) also called chilling injury (CI). This disorder is the main limitation to the marketing of some peach cultivars (Mitchell and Kader, 1989). Because these symptoms normally appear after ripening fruit at room temperature following cold storage, this problem is usually experienced by the consumers, not the growers, packers and/or buyers (Crisosto et al., 1997; Von Mollendorff, 1987).

Among IB susceptible peach cultivars, the greatest expression of the IB symptoms occurs after storage at temperatures between 36 and 46 °F (2.2 and 7.8 °C) (Haller, 1952; Harding and Haller, 1934; Mitchell and Kader, 1989; Smith, 1934). This range of temperatures has been named the killing temperature range because of its adverse effect on tree fruit market life (Crisosto, 1997). While IB symptoms will still develop at 32 °F (0.0 °C) or below, they develop more slowly and normally these symptoms become less intense than at higher temperatures. Unfortunately, in our study of fruit pulp temperatures after 3 d of domestic transportation we found that 80% of the peach shipments arrived within the killing temperature range. In most of the IB susceptible peach cultivars, market life is dramatically reduced when fruit are exposed to this temperature range for 3 to 7 d. For example, 'Elegant Lady' peach market life can be reduced from at least 3 weeks at 32 °F to only 1 week by exposing fruit to 41 °F (5.0 °C) for 5 to 7 d (Crisosto et al., 1999b). 'O'Henry' peaches developed visual mealiness symptoms after 2 weeks storage at 41 °F; however, trained judges were able to detect off-flavors or mealy texture 1 week before the visual symptom appeared. The early loss of flavor or off-flavor development demonstrates the significance of this problem to the consumer. With 'O'Henry' peaches, flesh browning was observed after week 3, ≈1 week later than mealiness symptoms (Crisosto and Labavitch, 2002). The role of temperature in IB symptom expression is important, but genetic background (Anderson, 1979; Crisosto et al., 1999a; Harding and Haller, 1934), maturity (Von Mollendorff, 1987), and orchard factors (Crisosto et al., 1994, 1997, 1999b) are also involved.

The current University of California recommendations for IB susceptible peaches are to cool the fruit pulp to near 32 °F within 8 h of harvesting, keep fruit at this temperature, and avoid exposing the fruit to the killing temperature range (Mitchell, 1987). Based on this information, a temperature management protocol for packers and shippers and a ripening protocol for fruit handlers and retailers has been developed (Crisosto, 1997; Mitchell and Kader, 1989). However, temperature management becomes difficult during the hot months of July and August when large volumes of IB susceptible peaches are harvested in California and transported out of state. These cultivars are routinely exposed to the killing temperature range during transportation and/or retail handling, and our current recommendations to reduce IB have not solved the problem in many cases.

Delayed cooling and/or intermittent warming treatments (Anderson, 1979; Nanos and Mitchell, 1991) were promising in controlling IB. Our work consisted of developing a commercially viable controlled delayed cooling protocol based on this concept.

Materials and methods

During the 1999 season, controlled delayed cooling experiments were conducted with three important freestone peach cultivars: 'Flavorcrest', 'Elegant Lady', and 'O'Henry'. In the 2000 season, 'Summer Lady', 'Zee Lady', and 'Ryan Sun' freestone peaches were evaluated. In both seasons, size 50 [≈6.6 oz (186 g)] peaches were washed, brushed, and coated with a mix of mineral wax and iprodione fungicide to prevent storage disease development, and packed into 24-lb (10.9-kg) boxes at a commercial packinghouse without cooling. After packaging, the boxes were transported 8 km to the University of California, Postharvest Laboratory at the Kearney Agricultural Center, Parlier (KAC).

In 1999, we evaluated five delayed cooling temperature treatments. The treatments consisted of exposure of the fruit to temperatures of 41, 50 (10.0 °C), or 68 °F for 24 or 48 h. Fruit that were cooled to 32 or 41 °F within 8 h of harvest (no delay or fast cooling) were used as the control. During the 2000 season, we focused on the best preconditioning treatments selected from the 1999 season, 24 and 48 h at 68 °F, plus the no delay treatment. Three and five replications (boxes) per treatment were used in the 1999 and 2000 seasons, respectively. After receiving the fruit from the packinghouse, all of the boxes were put in a forced-air

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cooler with an air supply temperature of 32 °F. The pulp temperature of the fruit was monitored, and these fruit were removed when they reached their target delay temperature (68, 50, or 41 °F). After removal from the cooling tunnel, the boxes were transferred to a controlled temperature room set at the appropriate delay temperature and held there for the specified length of time (24 or 48 h). Control fruit that required cooling to 32 °F (no delay or fast cooling) remained in the forced air room until they reached a pulp temperature of ≈34 °F (1.1 °C) (≈6 h) before being placed in the 32 °F cold room. Following the required cooling delay of 24 or 48 h, treated fruit were forced air cooled to a storage temperature of either 32 or 41 °F for further quality and market life determinations.

Fruit quality was measured on the day of harvest as well as after the 24 and 48-h delays. Ten fruit from each of the three (1999) and five (2000) replications per treatment were used to determine fruit weight (g), overall red color (%), soluble solids concentration (% SSC), pH, titratable acidity (% malic acid), and firmness [pounds force (lbf)] of the fruit at both cheeks, tip, suture, and shoulder as previously described (Crisosto et al., 1994). Another 30 fruit from each replication per treatment were removed from storage on 10 d (1999) or 7 d (2000) intervals to measure firmness and market life according to our previously published protocol (Crisosto et al., 1999; Garner et al, 2001). After each storage period, the fruit were warmed to room temperature and flesh firmness of 15 fruit per replication-treatment was evaluated immediately. The remaining 15 fruit per replication-treatment were kept in a ripening room at 68 °F with 85% humidity to trigger ripening for subsequent internal breakdown evaluation. Firmness changes during fruit ripening were monitored. When firmness reached 2 to 4 lbf (8.9 to 17.8 N), fruit were evaluated for internal breakdown symptoms. Two different market life potentials were calculated for each cultivar (Crisosto et al., 1999). The maximum market life was the number of weeks a cultivar could be stored under optimal conditions (32 °F) before IB symptoms became limiting, and the minimum market life was the number of the weeks it could be stored under poor conditions (41 °F). A cultivar was determined to have reached the end of its market life when ≥25% of the fruit became mealy or leathery, had flesh browning, or severe flesh bleeding (Nanos and Mitchell, 1991).

Results and discussion

FIRMNESS (1999 SEASON). Among the three cultivars tested during the 1999 season, neither SSC nor TA was significantly affected by any of the delayed cooling treatments (data not shown). Fruit flesh firmness at harvest and during storage depended on the position of measurement on the fruit. Among all cultivars in this test, the firmest position on the fruit was the cheek. For 'Flavorcrest' peaches, the softest position was at the suture; while for 'Elegant Lady' and 'O'Henry' peaches the softest position was at the shoulder. There was generally a 3 to 5 lbf (13.3 to 22.2 N) difference in flesh firmness between the firmest and softest positions. The preconditioning process led to varying degrees of flesh softening depending on temperature and duration, but the relative difference due to position of measurement generally remained (Table 1).

'Flavorcrest' peach cheek firmness decreased by about 5 lbf after the 48 h cooling delay at 68 °F. Although some softening occurred during the 24 h cooling delay at 68 °F and the 48 h cooling delay at 50 °F, peach cheek firmnesses were not significantly different from that of control fruit (Table 1). The softest suture firmness (4 lbf) occurred on fruit from the 48 h cooling delay treatment at 68 °F. Suture flesh firmness decreased by about 5 lbf during this delay treatment. Significant softening also occurred during the 24 h delay at 68 °F with a 3 lbf decrease in suture firmness. The highest suture firmness was measured on fruit immediately cooled and fruit from the 41 °F delay cooling treatments (24 or 48 h delay). Immediately cooling to 32 °F after preconditioning stopped any further flesh softening in all of the preconditioning treatments during subsequent storage at 32 °F. After 20 d storage at 32 °F, fruit from the 48 h delayed cooling treatment at 68 °F still had the lowest fruit firmness measured on the cheek [6.5 lbf (28.91 N)] and suture (4 lbf). Fruit from the 24 h delay at 68 °F and the 48 h delay at 50 °F were also significantly softer at the suture than control fruit.

At harvest and after the different delayed cooling treatments, the firmest position on 'Elegant Lady' and 'O'Henry' peaches was the cheek and the softest was the shoulder (Table 1). 'Elegant Lady' peaches lost about 7 lbf (31.1 N) firmness at the cheek and 5 lbf firmness at the shoulder during the 48 h cooling delay at 68 °F, while fruit cooled immediately or had cooling delayed for 24 h at 41 or 50 °F did not lose any flesh firmness. Fruit from the 24 h delay at 68 °F lost about 3 lbf at the cheek and 4 lbf at the suture during the cooling delay. Immediate cooling to a pulp temperature of 32 °F after the cooling delay treatments arrested further softening during subsequent 32 °F cold storage for all but the 48 h at 68 °F delay treatment. This treatment continued to soften between the 10 and 20 d storage period to a final flesh firmness of 4.9 lbf (21.80 N) at the cheek and 3.8 lbf (16.90 N) at the shoulder.

Similar rates of softening during preconditioning occurred with 'O'Henry' peaches. Fruit firmness was significantly affected by the temperature and length of exposure to the cooling delay treatments. The softest flesh firmnesses were measured on fruit from the 48 h cooling delay treatment at 68 °F, while firmnesses remained high in the other treatments. Unlike 'Elegant Lady' peaches, immediate cooling after preconditioning stopped further softening in all of the preconditioning treatments for 'O'Henry' peaches stored at 32 °F.

INTERNAL BREAKDOWN (1999 SEASON). In 1999, flesh browning and flesh bleeding symptoms were not observed in any of the preconditioned 'Flavorcrest', 'Elegant Lady' or 'O'Henry' peaches after 20 d storage at 32 °F. Although a low incidence of decay was observed, it was not significant or correlated with the treatments (data not shown). Flesh mealiness was not observed in any treatment after 20 d storage at 32 °F or 10 d at 41 °F (data not shown). After these storage periods, all fruit from the three cultivars were still juicy.

The incidence of mealiness increased dramatically after 20 d storage at 41 °F (Table 2). 'Flavorcrest' peaches from the 48 h cooling delay treatment at 68 °F had a significantly higher percentage of juicy fruit (93%) than the rest of the treatments (≤28% juicy fruit). None of the 'Flavorcrest' peaches that were immediately cooled were juicy after 20 d storage at 41 °F. With 'Elegant Lady' peaches, 97% of the fruit from the 24 and 48 h cooling delay treatments at 68 °F remained juicy

Table 1. Influence of controlled delayed cooling treatments on flesh firmness of three peach cultivars measured after treatments at 41, 50, or 68 °F (5.0, 10.0, or 20.0 °C), and 10 and 20 d of storage at 32 °F (0.0 °C) (1999 season).

Delayed cooling treatments	Firmness (lbf[z])					
	After treatment		10 d Storage		20 d Storage	
	Firmest position[y]	Softest position[x]	Firmest position	Softest position	Firmest position	Softest position
'Flavorcrest'						
No delay[w] (control)	11.4 a[v]	9.4 a	10.4 a	9.4 a	11.0	9.0 ab
24 h at 41 °F	11.0 a	9.5 a	10.6 a	8.5 a	9.7	7.8 abc
24 h at 50 °F	11.4 a	7.9 b	9.8 a	9.0 a	11.0	9.5 a
24 h at 68 °F	9.6 a	6.4 c	7.0 b	5.4 b	7.2	6.7 bc
48 h at 41 °F	11.1 a	9.4 a	9.8 a	8.2 a	10.1	7.4 abc
48 h at 50 °F	9.9 a	7.8 c	10.0 a	8.4 a	9.2	5.7 cd
48 h at 68 °F	6.5 b	4.0 d	6.0 c	5.3 b	6.0	3.7 d
P value	<0.0001	<0.0001	<0.0001	<0.0001	NS	0.004
'Elegant Lady'						
No delay (control)	14.6 ab	11.8 a	13.7 ab	11.0 ab	14.5 a	10.6 a
24 h at 41 °F	15.7 a	11.0 a	14.0 a	11.4 ab	12.9 abc	9.6 a
24 h at 50 °F	14.3 ab	10.8 a	14.0 a	11.6 a	14.2 a	10.6 a
24 h at 68 °F	11.2 c	7.8 bc	11.6 ab	10.3 ab	12.3 bc	9.3 a
48 h at 41 °F	13.9 b	10.6 a	14.7 b	11.4 ab	13.8 ab	10.6 a
48 h at 50 °F	10.9 c	8.2 b	12.4 a	10.2 b	11.4 c	9.6 a
48 h at 68 °F	7.7 d	6.4 c	7.1 c	4.9 c	4.5 d	3.8 b
P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
'O'Henry'						
No delay (control)	13.5 a	7.7 a	12.8 a	7.6 a	12.6 a	7.5 a
24 h at 41 °F	13.1 ab	7.7 a	12.3 abc	6.6 a	11.7 ab	6.9 ab
24 h at 50 °F	13.4 a	7.8 a	11.2 bc	6.5 a	9.1 bc	5.4 cd
24 h at 68 °F	12.1 bc	7.1 a	9.8 c	4.6 b	8.6 bcd	4.6 cd
48 h at 41 °F	11.4 c	7.6 a	12.7 ab	7.6 a	11.5 ab	6.5 ab
48 h at 50 °F	11.3 c	7.4 a	11.0 c	6.5 a	9.7 b	5.8 abc
48 h at 68 °F	7.5 d	4.1 b	7.5 d	4.4 b	6.5 d	3.9 d
P value	<0.0001	<0.0001	<0.0001	0.01	<0.0001	0.001

[z]1.0 pound force (lbf) = 4.448 N.
[y]The firmest position on the fruit for all cultivars was the cheek.
[x]The softest position on 'Flavorcrest' peaches was the suture; for all other cultivars it was the shoulder.
[w]Fruit were cooled to a pulp temperature of 32 °F within 6 to 8 h of harvest and maintained at this temperature.
[v]Mean separation by least significant difference test at $P > 0.05$.

after 20 d storage at 41 °F. Only 43% of the fruit that had been cooled immediately and stored at 41 °F remained juicy. Among fruit that had cooling delayed for 24 or 48 h at 50 °F, 68% and 46% remained juicy, respectively. Results for 'O'Henry' peaches were similar. All of the fruit from the 24 and 48 h cooling delay treatments at 68 °F remained juicy, and only 55% of the fruit that had been cooled immediately and stored at 41 °F remained juicy. Among fruit that had cooling delayed for 24 or 48 h at 50 °F, 78% and 77% remained juicy, respectively.

WEIGHT LOSS (1999 SEASON). Fruit weight losses measured during the treatment and storage periods were similar for the three cultivars evaluated (data not shown). For this reason, only the 'Elegant Lady' data will be discussed. Weight loss measured immediately after the delayed cooling treatments was very low in all of the treatments. Fruit from the 48 h cooling delay treatment at 68 °F lost the most weight (0.8%), while fruit that was immediately cooled lost the least (0.6%); but these differences are considered commercially unimportant. After 20 d of cold storage the amount of weight loss increased and ranged from 2.9% for fruit from the 48 h cooling delay treatment at 68 °F to 2.3% for fruit that were immediately cooled. In previous work (Crisosto et al., 1994) we found that peach shriveling symptoms became apparent when weight loss exceeded 10% of the initial fresh weight. The weight losses observed in this trial after the preconditioning

Table 2. Influence of controlled delayed cooling treatments at 50 or 68 °F (10.0 or 20.0 °C) on the percentage of 'Flavorcrest', 'Elegant Lady', and 'O'Henry' peaches remaining juicy after 20 d storage at 41 °F (5.0 °C) (1999 season).

Delayed cooling treatments	Juicy (%)		
	'Flavorcrest'	'Elegant Lady'	'O'Henry'
No delay[z] (control)	0 b[y]	43 b	55 b
24 h at 50 °F	7 b	68 ab	78 ab
24 h at 68 °F	28 b	97 a	100 a
48 h at 50 °F	20 b	46 b	77 ab
48 h at 68 °F	93 a	97 a	100 a
P value	0.001	<0.0001	0.01

[z]Fruit were cooled to a pulp temperature of 41 °F within 6 to 8 h of harvest and maintained at this temperature.
[y]Mean separation by least significant difference test at $P > 0.05$.

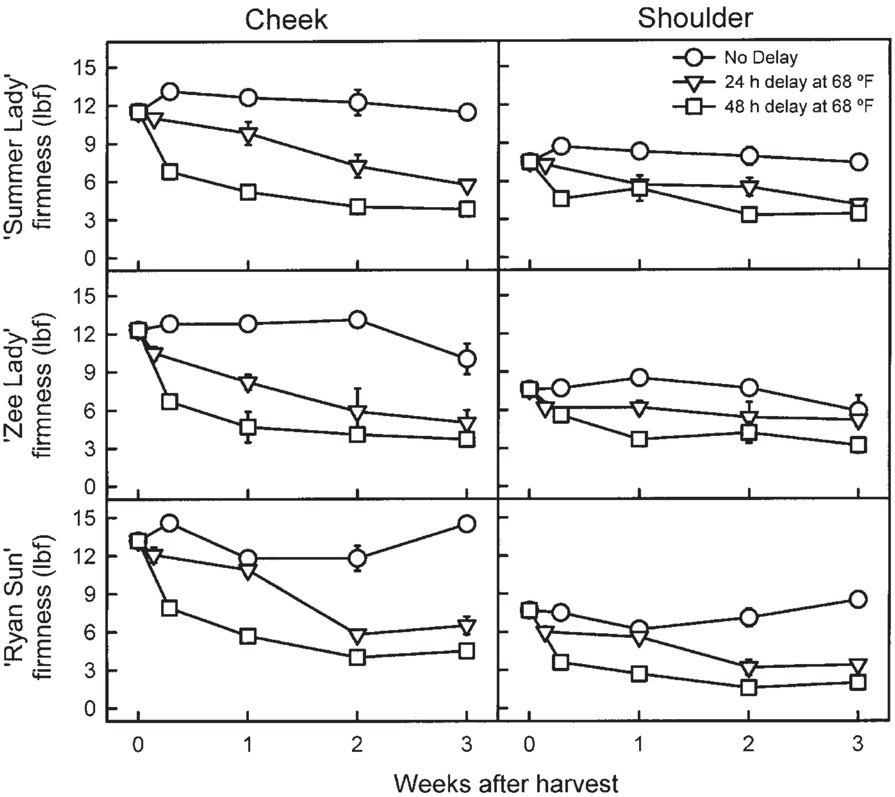

Fig. 1. Cheek and shoulder firmness of 'Summer Lady', 'Zee Lady', and 'Ryan Sun' peaches that were either immediately cooled or preconditioned at 68 °F (20.0 °C) for 24 or 48 h before storage at 32 °F (0.0 °C) for 3 weeks (2000 season). Vertical bars represent ± SE; 1 pound force (lbf) = 4.448 N.

treatments and subsequent 20 d cold storage at 32 °F did not cause any visible water loss symptoms. However, it is important to remember that water loss is cumulative with some percentage lost during harvest, and then more during packaging, storage, distribution, and marketing. For this reason, we recommended keeping weight loss to a minimum during the controlled delayed cooling treatment to assure an acceptable cosmetic presentation to consumers.

FIRMNESS (2000 SEASON). During the 1999 season, the cooling delay treatments at 68 °F were more effective than the delays at 41 or 50 °F in preventing the expression of internal breakdown symptoms after subsequent cold storage. Therefore, for the 2000 season we eliminated the 41 and 50 °F delay treatments and compared the 24 and 48 h cooling delays at 68 °F to immediate cooling (no delay). For the three cultivars tested during the 2000 season, neither SSC nor TA were significantly affected by any of the delayed cooling treatments (data not shown).

Fruit flesh firmness at harvest and during storage was again found to be dependent upon the position of measurement on the fruit. For 'Summer Lady', 'Zee Lady', and 'Ryan Sun' peaches the firmest position on the fruit was the cheek and the softest was the shoulder. There was generally a 3 to 5 lbf difference in flesh firmness between the firmest and softest positions. Changes in fruit flesh firmness measured during the cooling delay period and subsequent cold storage (32 °F) were similar to those observed in 1999. During the 48 h controlled delayed cooling period at 68 °F, 'Summer Lady' peach flesh firmness decreased about 5 lbf at the cheek and 3 lbf at the suture. During the subsequent 3 weeks cold storage at 32 °F fruit from this treatment lost an additional 3 lbf at the cheek and 1 lbf (4.4 N) at the suture (Fig. 1). Fruit from the 24 h delayed cooling treatment did not soften significantly during the delay period. They did, however, soften at a steady rate during the subsequent 3 weeks storage at 32 °F. During this time they lost about 5 lbf at the cheek and 3 lbf at the suture. Control fruit immediately cooled to 32 °F did not soften appreciably during the entire 3 week cold storage period.

'Zee Lady' and 'Ryan Sun' peaches followed a similar pattern of changes in flesh firmness during preconditioning and storage (Fig. 1). Fruit preconditioned for 48 h at 68 °F had a large initial decrease in flesh firmness during the delay period, but little more during subsequent storage at 32 °F. Peaches preconditioned for 24 h at 68 °F did not have a large initial decrease in flesh firmness, but instead lost firmness steadily during the entire storage period. After 2 to 4 weeks storage at 32 °F, the flesh firmnesses of fruit preconditioned for 24 and 48 h at 68 °F were similar. In all cases, control fruit (no cooling delay) stored at 32 °F did not soften appreciably during cold storage.

INTERNAL BREAKDOWN (2000 SEASON). In 2000, flesh bleeding symptoms were not observed in any of the preconditioned 'Summer Lady', 'Zee Lady' or 'Ryan Sun' peaches after 21 d storage at 32 or 41 °F. Although a low incidence of decay was observed, it was not significant or correlated with the treatments (data not shown).

Unlike the cultivars evaluated in 1999, two of the cultivars evaluated in 2000 developed internal breakdown symptoms during storage at 32 °F (data not shown). After 21 d storage at 32 °F, all of the 'Zee Lady' peaches from the 24 and 48 h cooling delay treatments at 68 °F were still juicy; whereas only

Table 3. Influence of controlled delayed cooling treatments at 68 °F (20.0 °C) on the percentage of 'Summer Lady', 'Zee Lady', and 'Ryan Sun' peaches remaining juicy after 21 d storage at 41 °F (5.0 °C) (2000 season).

Delayed cooling	Juicy (%)		
treatments	'Summer Lady'	'Zee Lady'	'Ryan Sun'
No delay^z (control)	53	7 a^y	47 a
24 h at 68 °F	85	60 b	63 ab
48 h at 68 °F	85	70 b	100 b
P value	NS	0.059	0.011

^{z}Fruit were cooled to a pulp temperature of 41 °F within 6 to 8 h of harvest and maintained at this temperature.
^{y}Mean separation by least significant difference test at $P > 0.05$.

13% of the peaches from the control treatment were still juicy. In addition, 26% of the control fruit had flesh browning; yet <7% of treated fruit had flesh browning. After 21 d storage at 32 °F, all of the 'Ryan Sun' peaches from the 48 h cooling delay treatment, 93% of the peaches from the 24 h cooling delay treatment and 73% of the peaches from the control treatment were still juicy. Flesh browning was present in 40% of the control fruit. In this instance 27% of the fruit from the 24 h cooling delay treatment at 68 °F also had flesh browning, but none of the fruit from the 48 h cooling delay treatment at 68 °F had any flesh browning.

As was the case in 1999, all three cultivars evaluated in 2000 developed internal breakdown during storage at 41 °F. After 14 d storage at 41 °F, only 60% of the control 'Summer Lady' peaches were juicy while all of the fruit from the 24 and 48 h cooling delay treatments at 68 °F were still juicy (data not shown). Results were similar after 21 d storage at 41 °F with 53% of the control fruit remaining juicy and 85% of the peaches from the 24 and 48 h cooling delay treatments still juicy (Table 3). In addition, 60% of the control fruit developed flesh browning, whereas none of the fruit from the delay treatments did.

'Zee Lady' peaches also developed internal breakdown symptoms after 14 d storage at 41 °F. At this time, only 33% of the control fruit (no delay) were still juicy. All of the fruit from the 24 and 48 h cooling delay treatments at 68 °F were still juicy after 14 d at 41 °F. In addition, 40% of the control fruit, 27% of the fruit from the 24 h delay and none of the fruit from the 48 h delay had flesh browning after 14 d storage at 41 °F (data not shown). After 21 d storage at 41 °F, >60% of the 'Zee Lady' peaches from the 24 and 48 h cooling delay treatments were still juicy, while only 7% of the control fruit were juicy (Table 3). At this time, 73% of the control fruit, 67% of the fruit from the 24 h cooling delay and none of the fruit from the 48 h cooling delay had flesh browning (data not shown).

'Ryan Sun' peaches began to develop internal breakdown symptoms after 14 d storage at 41 °F (data not shown). On this evaluation date, 60% of the control fruit (no delay) and 100% of the fruit from the 24 and 48 h cooling delay treatments remained juicy. Flesh browning also developed in the control treatment (40% of the fruit) and 24 h cooling delay treatment (27% of the fruit), but not the 48 h cooling delay treatment. After 21 d storage at 41 °F, 47% of the control fruit (no delay) and 63% of the fruit from the 24 h cooling delay treatment at 68 °F were still juicy. All of the peaches from the 48 h cooling delay at 68 °F remained juicy after 21 d at 41 °F. The incidence of flesh browning also increased to 73% in the control treatment and 67% in the 24 h cooling delay treatment, but was still not present in the 48 h cooling delay treatment.

MARKET LIFE (1999–2000 SEASONS). To make the results of this research more useful to our industry, we have expressed the effect of the cooling delay treatments on the market life of each cultivar under good conditions (32 °F – maximum market life) or poor conditions (41 °F – minimum market life) relative to the control treatment (no cooling delay). In all cases, when ≥25% of the fruit became mealy or had flesh browning, the market life of the fruit had ended (Nanos and Mitchell, 1991). The 48 h delayed cooling treatment at 68 °F extended maximum market life of 'Summer Lady' and 'O'Henry' peaches by 1 week and 'Ryan Sun' peaches by 2 weeks compared to fruit that had been cooled immediately (no delay) (Table 4). The 24 h cooling delay treatment at 68 °F had no effect on maximum market life. The 48 h cooling delay treatment at 68 °F also significantly extended minimum market life in all of the tested cultivars by at least 1 week (Table 4). The 24 h cooling delay treatment did increase the minimum market life of 'Summer Lady', 'Zee Lady' and 'Ryan Sun' peaches. The 24 h cooling delay at 68 °F was as effective as the 48 h delay at extending the minimum market life only of 'Summer Lady' and 'Zee Lady' peaches.

Controlled delayed cooling can be used to precondition stone fruit susceptible to internal breakdown in order to maintain flavor and extend market life. In general, a 24 to 48 h cooling delay at 68 °F was the most effective delayed cooling treatment to extend market life of internal breakdown susceptible peaches. Delayed cooling can also be used to preripen susceptible and nonsusceptible peaches in order to deliver a more ready-to-eat product to the consumer. However, weight losses and flesh firmness of the softest position on the fruit must be carefully monitored during the delayed cooling treatment.

As peaches soften during preconditioning, they become more susceptible to impact bruising and vibration injury during distribution. Critical bruising thresholds (CBT) based on fruit flesh

Table 4. Increase (↑) or decrease (↓) in market life of preconditioned peaches at 68 °F (20.0 °C) compared to untreated (no cooling delay) based on development of chilling injury (CI) during storage at 32 or 41 °F (0.0 or 5.0 °C).

Delayed cooling treatment	Change in maximum market life at 32 °F (weeks)	Change in minimum market life at 41 °F (weeks)
'Flavorcrest' (1999)		
24 h at 68 °F	0	0[1]
48 h at 68 °F	0	↑ 1+
'Elegant Lady' (1999)		
24 h at 68 °F	0	0
48 h at 68 °F	0	↑ 1+
'Summer Lady' (2000)		
24 h at 68 °F	0[1]	↑ 2[1,2]
48 h at 68 °F	↑ 1+	↑ 2[1,2]
'O'Henry' (1999)		
24 h at 68 °F	0[1]	0[1]
48 h at 68 °F	↑ 1+	↑ 1+
'Zee Lady' (2000)		
24 h at 68 °F	0	↑ 1+
48 h at 68 °F	0	↑ 1+
'Ryan Sun' (2000)		
24 h at 68 °F	0[1]	↑ 1[1,2]
48 h at 68 °F	↑ 2+	↑ 2[2]

[y]End of market life based on chilling injury determined when >25% of the fruit became mealy or leathery[1], or had flesh browning[2]. Superscript indicates limiting condition.

firmness and the forces of potential impacts they may encounter during postharvest handling have been developed for the most popular peach cultivars in California (Crisosto et al., 2001). These CBT values predict how much physical abuse the fruit will tolerate during packinghouse operations at different levels of flesh firmness. In general, yellow flesh peaches should be harvested and packaged at flesh firmnesses above 8 lbf (35.6 N) measured at the softest position. As peaches may soften to less than 8 lbf during the controlled delayed cooling treatment, they must be tray packed beforehand to protect them from the physical damage they may encounter during packaging. When flesh firmness measured at the softest position is <5 lbf, peaches become more susceptible to transportation (vibration) injury (Crisosto, unpublished data). In addition to increasing peach susceptibility to bruising, the controlled delayed cooling treatment can also increase the incidence of fruit decay and shrivel (Mitchell and Kader, 1989.). For this reason, a mixture of U.S. Environmental Protection Agency (EPA) approved fungicide and wax should be applied during packaging, before the controlled delayed cooling treatment.

Currently, there are several companies that are offering high quality preconditioned fruit based on this controlled delayed cooling treatment. This new system allows for the delivery of peaches to retail stores that are ready to buy [≈6 to 8 lbf (26.7 to 35.6 N) flesh firmness measured on the cheek]. These fruit have an extended market life, based on the occurrence of internal breakdown symptoms, and a high consumer acceptance. This new fruit delivery system is one more approach to limit internal breakdown and protect the fruit eating experience for consumers.

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