Controlled Atmosphere Storage and Aminoethoxyvinylglycine Postharvest Dip Delay Post Cold Storage Softening of 'Snow King' Peach

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Summary. 'Snow King' peaches (*Prunus persica*) harvested at commercial maturity were subjected to different carbon dioxide (CO_2) and oxygen (O_2) atmosphere combinations for a 2-week simulated transportation [0 °C (32 °F)] period after 1 week of cold storage in air (0 °C). In 1998, air or 5%, 10%, 15%, or 20% CO_2 combined with 3% or 6% O_2 were used during shipment. The trial was repeated in 1999, but for this year half of the fruit were treated with a 50 $mg \cdot L^{-1}$ (ppm) aminoethoxyvinylglycine (AVG) postharvest dip before storage and simulated shipment. In addition, O_2 levels during simulated shipment were reduced to 1.5% and 3%. At harvest and after the 2-week simulated shipment, fruit flesh firmness, soluble solids concentration (SSC), titratable acidity (TA), and chilling injury (CI) were evaluated. For both years, there were no significant differences in quality attributes among the different treatments after the simulated shipment period. SSC and TA did not change during 5 days postshipment ripening at 20 °C (68 °F). In 1998 all treatments softened rapidly during the postshipment ripening at 20 °C, and were ready to eat [13 N (1 N = 0.225 lb force)] after 3 days. In 1999, both the high CO_2 atmospheres during shipment and the AVG postharvest dip slowed the rate of softening during subsequent ripening at 20 °C. With respect to fruit softening, there was significant interaction between storage atmosphere and AVG treatment. AVG-treated fruit shipped under a 20% CO_2 + 3% O_2 atmosphere did not soften to the transfer point (firmness = 27 N) within our 5-day ripening period, while fruit not treated with AVG and shipped under the same atmosphere softened to the transfer point in 3 days. Control fruit (no AVG + air shipment) softened to the transfer point in 2 days. Our previous work found that when white flesh peaches soften to less than 27 N firmness they become very susceptible to impact bruise injury during retail distribution. We call this critical level of fruit flesh firmness the transfer point. Symptoms of CI, low O_2, or high CO_2 injury were not observed in any treatment in either year.

Recently, total production of white flesh peaches has increased rapidly. California white flesh peach and nectarine production has increased from 778,000 boxes [11.3-kg (25-lb) boxes] in 1996 to 7,009,626 boxes in 2000 (Calif. Tree Fruit Agreement, unpublished data). This amounts to about 17% of the total California peach and nectarine industry. In general, these cultivars have a lower titratable acidity than yellow flesh cultivars, although the acidity levels vary significantly among them (Crisosto et al., 2001a; Day et al., 1997). These low acid levels make white flesh stone fruit popular in the Asian markets, especially Taiwan. In the 2000 season, it was estimated that 91% of the 3.5 million boxes of peaches and nectarines exported to Taiwan were from white flesh cultivars (California Tree Fruit Agreement, unpublished data). Refrigerated container shipments to Taiwan, Hong Kong, and Japan take about 11 to 16 d. Rapid softening and deterioration of white flesh peaches at arrival and during distribution in Taiwan and Hong Kong have been observed. In our previous work, we found that when white flesh

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peaches softened to less that 27 N firmness, they became very susceptible to impact bruise injury during the distribution process (Crisosto et al., 2001b). Therefore, we recommended that these fruit be moved to the point of sale before they soften below this critical level of fruit firmness.

Some shippers transport white flesh stone fruit under controlled atmosphere conditions (17% CO_2 + 6% O_2) in an attempt to maintain fruit firmness at arrival and during distribution and marketing. Questions have arisen, however, as to whether the atmospheres they are using are beneficial or causing injury. Current recommendations for cling peach controlled atmospheres during shipment are to avoid O_2 concentrations less than 1% and CO_2 concentrations equal to or higher than 5%. For nectarine and freestone peach cultivars, it is recommended to avoid O_2 concentrations lower than 1% and CO_2 concentrations higher than 10% (Kader, 1997). Detailed CA recommendations for 'O'Henry' and 'Elegant Lady' peaches have been developed in California (Crisosto et al., 1999a). Little work on CA requirements of the white flesh stone fruit cultivars grown in California has been done. Work done in Japan (Kajiura, 1973; Kajiura and Iwata, 1971a, 1971b) indicated that O_2 concentration equal to or lower than 3% and/or CO_2 concentration equal to or higher than 10% injured 'Okubo' white flesh peaches. The susceptibility of stone fruit to chilling injury (CI) or internal breakdown is a further complication. CI can be easily confused with low oxygen and/or high carbon dioxide injury in stone fruit (Wang et al., 1990). Chilling injury is observed as a change in fruit flesh texture (hard, mealy or dry texture) and/or browning of the flesh. Flesh browning usually begins in the pit cavity, advances outward, and does not affect the skin (Crisosto et al., 1999b). Low O_2 and/or high CO_2 injury is normally seen as a browning of the skin and flesh. It usually progresses from the outside of the fruit inward. Also, chilling injury usually expresses itself during ripening following low temperature storage, whereas low oxygen injury can appear anytime during storage.

Another conceivable strategy to prevent rapid softening of white flesh stone fruit would be to metabolically inhibit endogenous ethylene production. Ethylene is the plant growth regulator produced by stone fruit coincident with ripening. Amino-ethoxyvinyl-glycine (AVG) blocks the conversion of methionine to 1-aminocyclopropane-1-carboxylic acid (ACC) and thereby stops ethylene production in plant tissues (Yu and Yang, 1979). The chemical is used in the apple industry to prevent fruit drop (Masia et al., 1998). When 176 to 10,000 $mg \cdot L^{-1}$ AVG was applied to 'Cresthaven' and 'Bisco' peaches and 'Redgold' nectarines as a postharvest dip, Byers (1997) found that AVG-treated fruit softened more slowly at room temperature [24 °C (75 °F)] than did control fruit.

In 1998 and 1999, we tested whether shipping white flesh peaches in a high CO_2 or low O_2 atmosphere could slow rapid fruit softening during simulated distribution and marketing. We also evaluated whether these controlled atmosphere shipments could cause damage to the fruit themselves. In addition, in 1999 we studied whether an AVG postharvest dip could slow the rapid softening observed after shipment. Thus, the objective of this research was to evaluate the influences of CO_2 and O_2 atmosphere combinations and AVG on white flesh peach quality attributes with an emphasis on fruit softening.

Materials and methods

1998 Season. Medium-size [220-g (0.49-lb)] 'Snow King' white-flesh peaches, harvested at commercial maturity, were collected from the packinghouse immediately after packing. This midseason cultivar was chosen because it is not susceptible to CI, thus making it easy to identify potential high CO_2 or low O_2 injury to the fruit's flesh. During packing, iprodione (Rovral, Aventis Cropscience, Research Triangle Park, N.C.) fungicide and wax were applied to the fruit. Fruit were immediately transported to the F. Gordon Mitchell Postharvest Laboratory at the Kearney Agricultural Center, Parlier, Calif., and forced air-cooled overnight to a pulp temperature of about 0 °C. After cooling, the fruit were stored at 0 °C for 5 d. After this storage period, the fruit were divided into nine treatments each replicated three times. The packed fruit were stored at 0 °C in 338-L (89.3-gal) sealed aluminum tanks under a continuous flow of either ethylene-free air or in CA where the CO_2 was 5%, 10%, 15%, or 20% and the O_2 was 3% or 6%. Flow rates and gas mixtures were established using a mixing board with micrometering valves. Supply and exhaust gas O_2 and CO_2 composition was monitored using a gas chromatograph (Carle model AGC-111; Chandler Engineering Co., Tulsa, Okla.) equipped with a thermal conductivity detector or an paramagnetic oxygen analyzer (model S-3A/II; Ametek Thermox, Pittsburgh, Pa.) and an infrared carbon dioxide analyzer (model VIA-510; Horiba, Irvine, Calif.). Ethylene was measured using the gas chromatograph with a flame ionization detector.

After 14 d simulated shipment at 0 °C, the fruit were removed and three replications of 15 fruit each were evaluated immediately. The remaining 45 fruit per replication were allowed to ripen at 20 °C and subsamples were evaluated after 1, 3, and 5 d. Quality attributes measured on each evaluation date included fruit firmness, soluble solids concentration (SSC), and titratable acidity (TA). First, the skin from opposite cheeks, tip, suture, and shoulder of each fruit was removed and the firmness measured using a U.C. firmness tester with a 7.9-mm (5/16-inch) tip. Then, a longitudinal wedge (from stem end to calyx end) was removed from each fruit, pressed through cheesecloth, and the SSC of the juice was measured with a temperature compensated refractometer (model ATC-1; Atago Co., Tokyo, Japan). Juice from each replication was pooled to form a composite sample,

Table 1. Initial quality attributes of 'Snow King' peaches.

Quality attribute	1998	1999
	Flesh firmness (N)[z]	
Cheek	45.4	53.4
Tip	48.0	60.5
Suture	31.6	48.0
Shoulder	37.4	42.3
Soluble solids concentration (%)	9.4	11.5
Titratable acidity (% malic acid)	0.33	0.27
Sugar-to-titratable acid ratio	28.5	42.6

[z]1.0 N = 0.225 lb force.

and TA was measured with an automatic titrator (Radiometer, Copenhagen, Denmark). On the last evaluation date, symptoms of low O_2 and high CO_2 damage as well as chilling injury symptoms were evaluated (Crisosto et al., 1999b). Chilling injury symptoms were evaluated as flesh browning (score 1 to 6; 1 = no browning, 6 = severe browning), texture (juicy, mealy, leathery), and bleeding (light, moderate, severe).

1999 SEASON. Medium-size [200-g (0.44-lb)] 'Snow King' white-flesh peaches were obtained from a commercial packinghouse as previously described. Peaches were divided into 2 main groups. One group was left untreated and the other dipped for 60 s in 50 mg·L^{-1} AVG. After dipping, the fruit were allowed to air dry at 20 °C. Then, all of the fruit were cooled overnight to a pulp temperature of about 0 °C. After cooling, the fruit were stored at 0 °C for 5 d then under a continuous flow of either ethylene-free air or CA where the CO_2 was 5%, 10%, 15%, or 20% and the O_2 was 1.5% or 3%.

All of the fruit were removed from the simulated shipment after 18 d. Fifteen fruit from each treatment were evaluated for firmness, SSC, and TA immediately as previously described. The remaining fruit were ripened in air at 20 °C. Fruit from each treatment were evaluated after 1, 3, and 5 d ripening for flesh firmness, SSC, TA, low O_2 and high CO_2 injury, and CI symptoms as previously described. In addition, the rate of ethylene production of a subsample of control and AVG-treated fruit that had been stored in air was measured during the ripening period using a flowing system. Peaches were enclosed in glass respiration jars attached to a flowboard. Airflow through the sample jars was adjusted with micrometer valves so that the internal atmosphere contained no more than 0.3% CO_2. Samples were withdrawn from the jars daily for 8 d, and ethylene content was determined as previously described.

Data were subjected to analysis of variance. Means were separated using LSD at the 5% level. The SAS statistical software (SAS Institute, Cary, N.C.) was used for these analyses.

Results and discussion

1998 SEASON. 'Snow King' peaches had a SSC of 9.4%, a TA of 0.33%, and a sugar-to-acid ratio (SSC:TA) of 28.5 at harvest (Table 1). Fruit flesh firmness at harvest varied on each fruit by as much as 13 N depending on the position of the measurement. The cheek (45.4 N) and tip (48.0 N) were the firmest positions on the fruit. The fruit's suture (31.6 N) and shoulder (37.4 N) were the softest positions. SSC, TA, and SSC:TA were not affected by the CA during simulated shipment or subsequent ripening at 20 °C (data not shown). High CO_2 and O_2 combination treatments did not significantly affect fruit firmness measured at any position on the fruit after 5 d cold storage plus 14 d simulated shipment. Peaches from all treatments softened rapidly at 20 °C following the simulated shipment (Fig. 1). After 3 d ripening, the firmness of fruit from all of the treatments was below 13 N (soft). 'Snow King' peaches did not develop any symptoms of CI or low O_2/high CO_2 toxicity during the evaluation period (data not shown).

1999 SEASON. 'Snow King' peaches had a SSC of 11.5%, a TA of 0.27%, and a SSC:TA of 42.6 at harvest (Table 1). As in 1998, fruit flesh firmness at harvest varied on each fruit by as much as 17.8 N depending on the location of the measurement. The cheek (53.4 N) and tip (60.5 N) were the firmest positions on the fruit. The fruit's suture (48.0 N) and shoulder (42.3 N) were the softest positions. SSC, TA, and SSC:TA were not affected by the post-

Table 2. Fruit flesh firmness, soluble solids concentration (SSC), titratable acidity (TA), and sugar-to-acid ration (SSC:TA) of control and aminoethoxyvinylglycine (AVG) treated 'Snow King' peaches after 5 d storage at 0 °C (32 °F), followed by 18 d simulated controlled atmosphere shipment at 0 °C.

	Flesh firmness (N)[z]						
Treatment	Cheek	Tip	Suture	Shoulder	SSC (%)	TA (%Malic)	SSC:TA
AVG[y]							
50 mg·L^{-1} dip	50.3	54.3	41.8	40.5	13.5	0.24	57.8
Untreated	49.8	52.5	41.4	40.5	13.5	0.25	55.0
P	0.53	0.16	0.24	0.84	0.89	0.13	0.11
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS
Storage atmosphere							
5% CO_2 + 1.5% O_2	48.0	52.0	39.6	39.6	12.9	0.25	51.6
5% CO_2 + 3.0% O_2	50.7	56.0	42.7	42.3	13.5	0.21	63.6
10% CO_2 + 1.5% O_2	51.6	54.7	42.3	42.3	14.0	0.25	56.7
10% CO_2 + 3.0% O_2	49.4	53.4	41.4	39.1	14.3	0.27	52.9
15% CO_2 + 1.5% O_2	49.8	55.2	43.1	40.5	13.8	0.25	56.9
15% CO_2 + 3.0% O_2	49.8	50.3	40.9	40.0	13.5	0.25	54.9
20% CO_2 + 1.5% O_2	51.6	53.8	42.3	42.3	13.1	0.25	53.0
20% CO_2 + 3.0% O_2	48.0	52.5	40.9	39.6	13.6	0.25	51.6
Air	50.7	53.4	41.4	40.0	13.1	0.21	63.7
P	0.27	0.23	0.55	0.24	0.29	0.1	0.083
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS	NS
AVG × storage atmosphere							
P	0.47	0.39	0.37	0.17	0.21	0.32	0.39

[z]1.0 N = 0.225 lb force.
[y]50 mg·L^{-1} (ppm) postharvest dip, 60 s.

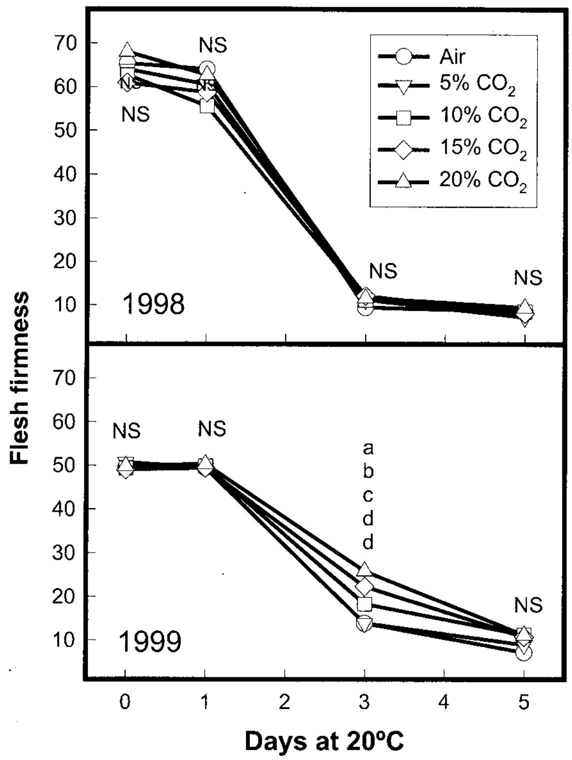

Fig. 1. Flesh firmness of 'Snow King' peaches during ripening at 20 °C (68 °F) following simulated controlled atmosphere shipment at 0 °C (32 °F), 1998–99 seasons. Oxygen atmosphere in CA (3% or 6% for 1998, and 1.5% or 3% for 1999) did not affect firmness, so these data were combined; 1 N = 0.225 lb force.

harvest AVG dip or CA storage conditions (data not shown). They did not soften during the 5 d storage plus 18 d simulated shipment at 0 °C, and flesh firmness was not affected by AVG or storage atmosphere during this period of time. Average cheek firmness at harvest was 53.4 N. Upon removal from CA storage, cheek firmness ranged from 48.0 to 51.6 N depending on treatment (Table 2). 'Snow King' peaches did not develop any symptoms of CI or low O_2/high CO_2 toxicity during the evaluation period (data not shown).

Fruit firmness after simulated shipment during ripening was not influenced by the O_2 concentration (1.5% or 3.0%) used during the simulated CA shipment (data not shown). Carbon dioxide concentration during simulated CA shipment affected the peach ripening pattern. After 3-d ripening at 20 °C, fruit that had been previously stored in high CO_2 atmospheres were firmer than fruit that were stored in lower CO_2 atmospheres (Fig. 1—the 1.5% and 3.0% O_2 atmospheres are combined to simplify presentation). Among fruit not treated with AVG, flesh firmness was 25.8, 22.2, 18.2, and 13.8 N after the 20%, 15%, 10%, and 5% CO_2 CA treatments, respectively. Flesh firmness of air stored fruit was 13.8 N after 3 d ripening. After 5 d ripening, all fruit not treated with AVG were ready to eat (<13 N), and there were no significant differences in firmness between fruit from the different CO_2 atmospheres.

There was a significant interaction with fruit firmness changes during ripening between the AVG treatment and the simulated shipment atmosphere. Fruit that had been treated with AVG and shipped under high CO_2 conditions remained firmer at both the cheek (Fig. 2) and shoulder (data not shown) during ripening at 20 °C than fruit that were either not treated with AVG or stored in lower CO_2 atmospheres. Previous work has shown that when the firmness of white flesh peaches drops below about 27 N, the fruit becomes more susceptible to bruising injury during handling during distribution (Crisosto et al., 2001b). For this reason, we recommend that fruit be moved to the point of sale before it reaches this transfer-point firmness. Most of the 'Snow King' peaches treated with AVG did not soften below 27 N on the cheek within our 5-d ripening period, while fruit not treated with AVG softened to the transfer point within 2 to 3 d (Table 3). The shoulder of 'Snow King' peaches tended to be softer than the cheek, so this position would be expected to be more susceptible to bruise injury. Peaches treated with AVG and shipped in 20% CO_2 + 1.5% O_2 did not soften to 27 N on the shoulder within our 5-d ripening period, while all fruit not treated with AVG softened to the transfer point within 2 to 3 d. In general, the higher the CO_2 concentration during the simulated shipment, the

Fig. 2. 'Snow King' peach softening at 20 °C (68 °F) for control and aminoethoxyvinylglycine (AVG) treated fruit after cold storage [5 d at 0 °C (32 °F)] and simulated controlled atmosphere shipment (18 d at 0 °C), 1999 season; 1 N = 0.225 pounds force.

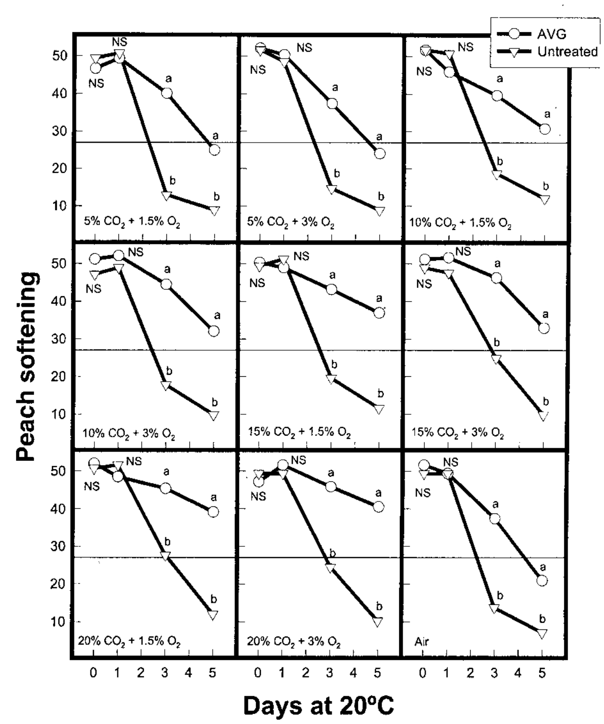

Table 3. Number of days ripening [20 °C (68 °F)] following cold storage [5 d at 0 °C (32 °F)] and simulated controlled atmosphere shipment (18 d at 0 °C) required before aminoethoxyvinylglycine (AVG) treated and control 'Snow King' peaches reach the transfer point flesh firmness [27 N (6 lb force)].

Simulated shipment atmosphere	Estimated number of days to reach 27 N			
	Cheek		Shoulder	
	AVG dipped[z]	Untreated	AVG dipped	Untreated
Air	4.1	1.9	3.4	1.6
5% CO_2 + 1.5% O_2	4.6	1.9	4.0	1.5
5% CO_2 + 3% O_2	4.5	2.0	3.3	1.7
10% CO_2 + 1.5% O_2	5.0+[y]	2.3	4.9	1.8
10% CO_2 + 3% O_2	5.0+	2.1	4.9	1.3
15% CO_2 + 1.5% O_2	5.0+	2.3	5.0+	1.7
15% CO_2 + 3% O_2	5.0+	2.8	4.6	1.8
20% CO_2 + 1.5% O_2	5.0+	3.1	5.0+	2.6
20% CO_2 + 3% O_2	5.0+	2.7	5.0	2.1

[z]Dipped in 50 $mg \cdot L^{-1}$ (ppm) aminoethoxyvinylglycine (AVG) for 60 s before storage.
[y]5+ indicates that the fruit did not soften to less than 27 N flesh firmness within our sampling period.

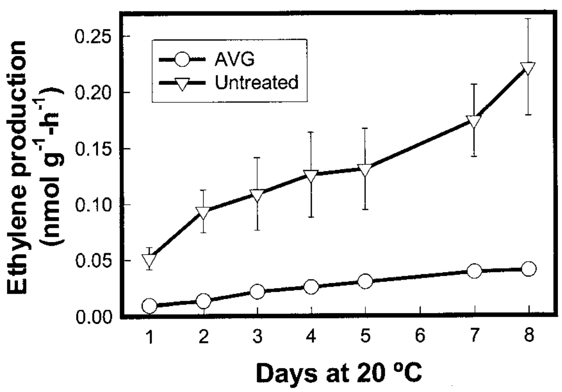

Fig. 3. Ethylene production rate of aminoethoxyvinylglycine (AVG) treated [50 $mg \cdot L^{-1}$ (ppm) dip, 60 s] and control 'Snow King' peach during ripening at 20 °C (68 °F) after cold storage [5 d at 0 °C (32 °F)] and simulated shipment in air (18 d at 0 °C), 1999 season. Vertical bars represent ±SE.

longer it took the fruit to soften to the transfer point. CA shipment in 15% to 20% CO_2 without AVG delayed fruit softening (cheek) at 20 °C to the transfer point by 1 d compared with shipment in atmospheres ≤10% CO_2.

Peaches treated with AVG produced less ethylene during ripening than untreated fruit (Fig. 3). Ethylene production of untreated peaches increased from 0.05 $nmol \cdot g^{-1} \cdot h^{-1}$ upon removal from storage to 0.22 $nmol \cdot g^{-1} \cdot h^{-1}$ after 8 d ripening at 20 °C. Ethylene production of AVG-treated fruit was 0.01 $nmol \cdot g^{-1} \cdot h^{-1}$ upon removal from storage and increased slightly to 0.04 $nmol \cdot g^{-1} \cdot h^{-1}$ after 8 d ripening. This inhibition of ethylene production during ripening corresponds with the retention of fruit flesh firmness.

In 1998 and 1999, we did not observe any indication of damage to 'Snow King' peaches resulting from storage in high CO_2 or low O_2 atmospheres for up to 18 d at 0 °C. High CO_2 levels during CA shipment delayed softening to the transfer point by 2 d during postshipment ripening at 20 °C. No CI was observed in 'Snow King' peaches, but for some susceptible yellow flesh cultivars CA shipment has been shown to delay its expression. The postharvest use of ethylene inhibitors such as AVG appears to be a promising tool that may replace CA as a way of preventing rapid softening of white flesh peaches during long-term shipment and distribution. The manufacturer of AVG (Valent Biosciences Corp., Libertyville, Ill.) is currently pursuing postharvest registration of their product.

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