Peach and Nectarine Fruit Softening Following Aminoethoxyvinylglycine Sprays and Dips

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Abstract: AVG sprays applied to 'Redhaven' peach (*Prunus persica* L. Batsch) trees 53, 72, 80, 87, or 94 days after full bloom (AFB) slightly delayed the first harvest date. Applications at 53 or 94 days AFB slightly delayed cumulative second and third harvests. The fourth (final) harvest was not delayed by any AVG spray. Firm commercial-harvest peach and nectarine fruit submerged for 60 s in AVG solutions softened more slowly than the controls when kept at room temperature ($\approx 24^\circ\text{C}$) for 3 to 12 days. AVG-treated fruit dipped in ethephon after 4 days showed an increased rate of softening compared to fruits treated only with AVG. Fruit submerged in AVG solutions and stored at 1.5 or 4.5 $^\circ\text{C}$ for 12 to 18 days did not differ in firmness from the controls upon removal from cold storage but sometimes softened more slowly after storage. Ethylene evolution from AVG-dipped fruit was not measurable even after it was kept at room temperature for 12 days. Chemicals used: Aminoethoxyvinylglycine hydrochloride (AVG); 2-chloroethylphosphonic acid (ethephon).

Peach and nectarine fruit are harvested commercially in the final swell of fruit development, when fruits are still adequately firm to resist bruising while being packed and shipped. Butanedioic acid mono (2,2-dimethylhydrazide) (daminozide) application to peach trees hastened fruit maturity and softening and generally concentrated peach harvest (Byers, 1969; Byers et al., 1972). Daminozide did not affect fruit growth rates, so yields were reduced because fruit were harvested a few days earlier in the final rapid phase of growth. In addition, low rates of ethephon applied to peach trees in early stage III accelerated fruit growth and hastened maturity (Byers et al., 1969). AVG applied after completion of rest and before bloom delayed flowering as much as 10 days, but had little effect on fruit size, color, firmness, soluble solids concentration (SSC), fruit acidity, or maturity (Dekazos, 1981).

AVG is an ethylene-biosynthesis inhibitor (Shafer et al., 1995; Yu and Yang, 1979) that suppresses ethylene production in apples (*Malus domestica* Borkh.) (Autio and Bramlage, 1982; Bangerth, 1978). When ap-

plied within 1 month of harvest, AVG delays fruit ripening, suppresses preharvest and postharvest flesh softening, reduces watercore, reduces preharvest fruit drop, and increases fruit removal force (Autio and Bramlage, 1982; Bangerth, 1978; Williams, 1980). If preharvest softening of peach and nectarine fruit could be delayed, it not only could provide growers more time for harvest but also might allow additional fruit growth and reduced physical damage. In addition, peaches and nectarines may be hydrocooled to slow the rate of softening prior to packaging or are immediately packed and shipped under refrigeration or precooled prior to shipment by placement in cold storage. AVG dips could provide an additional method for slowing postharvest softening.

The objectives of these experiments were to: 1) determine if preharvest AVG sprays delay preharvest peach softening, 2) determine if postharvest AVG application retards ripening and softening at room temperature immediately after harvest or after short periods of cold storage, and 3) accelerate ripening of AVG-treated fruit by application of ethephon.

Materials and Methods

AVG in orchard (Expt. 1). In 1992, 56 full-size 'Redhaven' peach trees were selected for uniformity of crop and were blocked according to row and terrain into seven blocks for eight treatments. The spray treatments were: 1) control (no AVG); 2–6) AVG at 500 $\text{mg}\cdot\text{L}^{-1}$ at 53, 72, 80, 87, or 94 days after full bloom (AFB), respectively; and 7–8) AVG at 125 or 250 $\text{mg}\cdot\text{L}^{-1}$ respectively, applied at 87 days AFB. The surfactant, Regulaid, at 0.125% was included in all AVG treatments to assist in

foliar wetting (Kalo; Overland Park, Kan.). The sprays were applied at 2244 $\text{L}\cdot\text{ha}^{-1}$ with a Swanson airblast sprayer (Durand-Wayland, LaGrange, Ga.) with two fans to one side. Fruit harvested from each tree were weighed on each of four picking dates—28 July, and 3, 7, and 11 Aug. Fruit were harvested when the ground color was light yellow. Ten such fruits were sampled randomly from each tree just before each picking for measuring fruit diameter and visually rating the percentage red surface color.

Postharvest AVG dips for 'Cresthaven' peaches (Expt. 2). About 500 firm-ripe (commercial harvest maturity) 'Cresthaven' peaches were harvested on 21 Aug. 1992. From these fruit, 13 groups of 20 fruit each were selected at random. One group was tested immediately for firmness and SSC. Three other groups were submerged for 60 s in aqueous solutions of AVG at 0, 2500, 5000, or 10,000 $\text{mg}\cdot\text{L}^{-1}$. All AVG solutions included Rovral 50W [3-(3,5-dichlorophenyl)-N-(1-methylethyl)-2,4-dioxo-1-imidazolidine-carboxamide (iprodione); Rovral 50W and Rovral 4F] at 1200 $\text{mg}\cdot\text{L}^{-1}$ to control fungi. Of the three groups of fruit tested with a given AVG concentration, one was placed on a laboratory bench for 3 days at 24 $^\circ\text{C}$, a second was kept on the bench for 5 days, and a third was placed in storage at 4.5 $^\circ\text{C}$ for 18 days (in a plastic storage liner to maintain a high and uniform relative humidity) and then on the bench for 1 day. Within each 20-fruit group, four subgroups of five fruit each were tested for flesh firmness and SSC. Flesh firmness was measured on two sides of each fruit with an Effegi penetrometer (model FT327; McCormick Fruit Tech, Yakima, Wash.) fitted with an 11.1-mm tip (7 N was about the minimum firmness that a fully ripe fruit attained). The SSC was estimated with an Atago hand-held refractometer (model N1; McCormick Fruit Tech) as a composite sample for four subgroups of five fruit each per treatment.

Postharvest AVG dips for 'Bisco' peaches (Expt. 3). About 1000 firm-ripe (commercial harvest maturity) 'Bisco' peaches were harvested on 22 Aug. 1995. From these fruit, 27 groups of 20 fruit each were selected at random. The design was an augmented factorial experiment with five AVG concentrations, five storage treatments, and two controls. Five groups of 20 fruit were submerged for 60 s in aqueous solutions of AVG at 0, 167, 333, 666, and 2664 $\text{mg}\cdot\text{L}^{-1}$. All solutions included Rovral 4F at 600 $\text{mg}\cdot\text{L}^{-1}$ for control of fungi and a surfactant [alkylaryl polyethoxylate and sodium salt of alkylsulfonatedalkylated (Latron CS-7, 60% a.i. mixture); Rohm Hass Co., Philadelphia] at 0.125% in aqueous solution. Four of these groups were placed on a bench for 4, 7, 12, or 15 days at 24 $^\circ\text{C}$. A fifth group was placed on the bench for 4 days submerged in ethephon at 250 $\text{mg}\cdot\text{L}^{-1}$ for 60 s, and kept on the bench for 3 more days. At the end of each time period, fruit were tested for flesh firmness and SSC as in Expt. 2. Ethylene evolution of 10 peach fruits (≈ 1.7 kg) was determined by sealing them in a gas-tight 4.5-L chamber. A

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head space sample was withdrawn after 1 h and ethylene was measured by gas chromatography (Varian 3700, Sugar Land, Texas).

Postharvest AVG Dips for 'Bisco' peaches (Expt. 4). About 1000 firm-ripe (commercial harvest maturity) 'Bisco' peaches were harvested on 22 Aug. 1995. From these fruit, 27 groups of 20 fruit each were selected at random. Two of these groups were immediately tested for firmness and SSC. One group was submerged for 10 s in aqueous AVG solutions at 0, 42, 83, 167, or 333 mg·L⁻¹. All solutions included Rovral 4F at 600 mg·L⁻¹ to control fungi and a surfactant (Latron CS-7) at 0.125% in aqueous solution. An additional group was submerged for 60 s at each of these concentrations, and another for 300 s at each concentration. These 15 groups were placed on the bench for 5 days at 21 °C before being evaluated for flesh firmness and SSC as above. Another five groups were dipped for 60 s at this range of AVG concentrations, placed on the bench for 5 days as above, and then stored at 1.7 °C for 12 days plus 1 day at 24 °C before being tested. Another five groups were dipped for 60 s in the range of concentrations, placed in cold storage at 1.5 °C for 12 days (in a plastic storage liner to maintain a high uniform relative humidity), and then kept on the bench at 24 °C for 6 days before testing. Ethylene evolution was determined as above.

Postharvest AVG dips for 'Redgold' nectarines (Expt. 5). About 1000 'Redgold' nectarine fruit were harvested on 18 Aug. 1995 at a firm-ripe stage (commercial harvest maturity). These fruit were placed randomly in 27 groups of 20 peaches each. Two groups were tested immediately for firmness. Five groups of 20 fruit were submerged for 60 s in aqueous AVG solutions at 0, 167, 333, 666, and 2664 mg·L⁻¹. All solutions included Rovral 4F at 600 mg·L⁻¹ to control fungi and a surfactant (Latron CS-7) at 0.125% in aqueous solution, except where noted below. For each concentration, one group was placed on a bench for 3, 7, or 12 days at 24 °C. A fourth group was treated the same as group 3, but no surfactant was added to the solution. The fifth was stored at 1.5 °C for 12 days (in a plastic storage liner to maintain a high uniform relative humidity) and then on the bench at 24 °C for 7 days. At the end of each time period, fruit were tested for flesh firmness and SSC as above. Ethylene evolution was determined as above.

The AVG (Abbott Laboratories, Long Grove, Ill.) used in 1992 was technical powder (90.2% a.i.), and in 1995 it was a 15% a.i. formulation.

Analysis of variance (ANOVA) was used to determine the presence of main and interaction effects. When there was a significant concentration × storage interaction, concentration effects were then examined by regression analysis within each storage treatment. When there was no significant interaction, only main effects were examined. Data were analyzed by ANOVA and GLM procedures of the SAS 6.08 software package (SAS Institute, Cary, N.C.). The quadratic model presented contains the linear and quadratic terms.

Results and Discussion

AVG in orchard (Expt. 1). Spray applications of AVG at 500 mg·L⁻¹ to peach trees from the end of stage I to mid-stage III of fruit growth had almost no effects on cumulative percentage of fruit harvested at each picking date, fruit diameter, or percentage of red surface color (data not shown). Since ethephon applied to peach trees in stage III of fruit growth is known to stimulate fruit growth rate and hasten maturity, whole-tree application of AVG, an ethylene biosynthesis inhibitor, was expected to delay the normal harvest date; this did not occur at the rates used. However, AVG appeared to have entered the peach tree, since side branching of the current season's axillary buds occurred when applications were made 53 to 80 days AFB (personal observation). Curry and Williams (1986) found that AVG treatments increased branching of apple trees. Over all, whole-tree sprays did not produce commercial benefits.

Postharvest AVG dips for 'Cresthaven' peaches (Expt. 2). Postharvest softening of 'Cresthaven' peach fruit was slowed by submerging fruit in AVG solutions for 60 s (Table 1). SSC was unaffected (data not shown). AVG-treated fruit held in cold storage at 4.5 °C for 18 days plus 24 °C for 1 day were similar in firmness to nontreated controls (data not shown), and there was a significant linear increase in SSC ($P \leq 0.05$; $R^2 = 0.2398$).

Postharvest AVG dips for 'Bisco' peaches (Expt. 3). Postharvest softening of 'Bisco' Table 1. Effect of postharvest AVG dips on 'Cresthaven' peach firmness following storage at 24 °C (1992)* (Expt. 2).

AVG (mg·L ⁻¹)	Firmness (N)	
	Storage at 24 °C (days)	
	3	5
0	16	9
2,500	32	38
5,000	37	50
10,000	36	43
Regression		
L	**	NS
Q	**	**

*Fruit immediately after harvest had a firmness of 73 N.

NS, **Nonsignificant or significant regression at $P \leq 0.01$.

Table 2. Effect of postharvest AVG dips on 'Bisco' peach firmness and ethylene evolution at 24 °C (1995)* (Expt. 3).

AVG (mg·L ⁻¹)	Fruit firmness (N)					Ethylene (mg·L ⁻¹ ·h ⁻¹)		
	Storage at 24 °C (days)					Storage at 24 °C (days)		
	4	7	7 + E [†]	12	15	4	7	12
0	10	7	10	7	7	7.3	6.8	24.6
167	14	9	12	9	10	0.5	0.3	1.1
333	14	12	14	12	10	0.2	0.1	0.2
666	17	14	14	13	12	0.1	0.0	0.0
2664	23	20 ^x	14 ^x	16	16	0.0	0.0	0.0
Regression								
L	***	***	NS	***	NS	NS	NS	NS
Q	**	**	**	***	NS	*	*	*

*Fruit immediately after harvest had a firmness of 62 N.

[†]Fruit were dipped in 250 mg·L⁻¹ ethephon for 60 s on day 4 and kept at 24 °C for another 3 days.

^xContrast of ethephon applied at 4 days and kept at 24 °C for another 3 days vs. no ethephon with AVG at 2664 mg·L⁻¹ was significant at $P \leq 0.05$.

NS, *, **, ***Nonsignificant or significant regression at $P \leq 0.05$, 0.01, or 0.001.

peach fruit was slowed by submerging fruit in AVG solutions for 60 s (Table 2), but SSC was unaffected (data not shown). The higher the rate of AVG, the slower the loss of fruit firmness, and the more ethylene production was inhibited ('Bisco' peach, Table 2). Fruit treated with AVG at 2664 mg·L⁻¹, then dipped in ethephon after 4 days, softened faster than similar fruit without ethephon (Table 2, 7 vs. 7 + E). The presence of an external source of ethylene caused fruit to ripen in the presence of AVG.

Postharvest AVG dips for 'Bisco' peaches (Expt. 4). Postharvest softening of 'Bisco' peaches was slowed by submerging them in AVG solutions (Table 3), but SSC was unaffected (data not shown). Increasing rates of AVG reduced ethylene evolution and slowed loss of fruit firmness. All AVG rates greatly suppressed measurable ethylene evolution from fruit samples even after being kept at room temperature for 12 days. Presumably softening was caused by ambient ethylene levels in storage at 1.5 °C. Increasing dip time from 10 s to 300 s did not affect the effectiveness of AVG as measured by fruit firmness or ethylene evolution (Table 3).

Postharvest AVG dips for 'Redgold' nectarines (Expt. 5). When 'Redgold' nectarines were submerged in AVG solutions for 60 s, softening was delayed (Table 4). The dramatic delay in softening of 'Redgold' nectarine fruit still was evident after 12 days at 24 °C. AVG dips were more effective when the surfactant, Latron CS-7, was omitted, as measured by a significantly higher fruit firmness after 12 days at 24 °C, but the use of the surfactant did not affect ethylene production (Table 4). AVG at 666 mg·L⁻¹ and higher completely suppressed measurable ethylene evolution from fruit samples, even after they were held 6 days at 1.5 °C plus 12 days at room temperature (Table 4). AVG had very little effect on softening of fruit that were kept at 1.5 °C, but ethylene production was completely inhibited at the highest concentrations (Table 4). Presumably softening was caused by ambient ethylene levels in storage at 1.5 °C.

AVG had no effect on SSC in any of the 1995 experiments (data not shown).

In these experiments, postharvest applications of AVG significantly delayed softening of peaches and nectarines. This delay could

Table 3. Effect of postharvest AVG dips on 'Bisco' peach firmness and ethylene evolution at 24 °C (1995)² (Expt. 4).

AVG (mg·L ⁻¹)	Fruit firmness (N)					Ethylene (mg·L ⁻¹ ·h ⁻¹)		
	Storage at 24 °C					Storage at 24 °C		
	5 ^y			18 ^x	18 ^w	5 ^y		
	Duration of dip (s) ^y					Duration of dip (s)		
	10	60	300			10	60	300
0	9	7	8	7	7	9.9	12.4	8.9
167	14	9	13	7	7	1.0	1.1	0.7
333	14	10	15	7	7	0.5	0.7	0.4
666	12	14	14	8	7	0.4	0.6	0.5
2664	14	15	16	9	8	0.4	0.4	0.2
Regression								
L	*	***	***	***	*	NS	NS	NS
Q	NS	*	**	NS	NS	*	*	*

²Fruit immediately after harvest had a firmness of 62 N.^yFruits were dipped for 10 s, 60 s, or 300 s, respectively, and kept at 24 °C for 5 days.^xFruits were dipped for 60 s, and kept at 24 °C for 5 days, stored at 1.5 °C for 12 days, and then kept at 24 °C for 1 day before testing.^wFruits were dipped for 60 s, stored at 1.5 °C for 12 days, and then kept at 24 °C for 6 days before testing.NS, *, **, ***Nonsignificant or significant regression at $P \leq 0.05$, 0.01, or 0.001.Table 4. Effect of postharvest AVG dips on 'Redgold' nectarine firmness and ethylene evolution at 24 °C (1995)² (Expt. 5).

AVG (mg·L ⁻¹)	Fruit firmness (N)						Ethylene (mg·L ⁻¹ ·h ⁻¹) ^y			
	Storage at 24 °C(days)						Storage at 24 °C(days)			
	3	7	12	12 ^y	18 ^x	5	7	12	12 ^y	18 ^x
0	43	16	11	16	10	2.2	2.8	5.9	5.8	33.3
167	71	29	17	27	10	0.7	0.8	3.7	0.7	10.0
333	73	54	26	54	11	0.1	0.8	0.5	0.0	12.8
666	93	76	55	55	25	0.0	0.0	0.0	0.0	0.0
2664	91	82	63	79	17	0.0	0.0	0.0	0.0	0.0
Regression										
L	**	***	***	***	NS	NS	NS	NS	NS	NS
Q	***	***	***	***	***	*	*	*	*	*

²Fruit immediately after harvest had a firmness of 62 N.^ySurfactant, Latron CS-7, was omitted in this group of treatments.^xFruits were dipped for 60 s, stored at 1.5 °C for 12 days, then kept at 24 °C for 6 days before testing.NS, *, **, ***Nonsignificant or significant regression at $P \leq 0.05$, 0.01, or 0.001.

allow additional time for transport and marketing and may reduce physical damage. Further studies are needed to determine if AVG-treated fruit will soften to acceptable quality in a reasonable time once in the marketplace. Studies may be needed to develop methods for initiating softening of AVG-treated fruit with exogenous treatments.

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