

Postharvest Treatments to Reduce the Harmful Effects of Ethylene on Apricots

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Abstract

'Patterson' and 'Castlebrite' apricots were dipped for 1 min in aqueous solutions at 20°C containing 0, 6.25, 12.5, 25, or 50 ppm aminoethoxyvinylglycine (AVG) and held at 20°C for a 5-day ripening period. Fruit softening was delayed and ethylene production was reduced on AVG-treated fruit, particularly in the case of 'Patterson' apricots, which produced more ethylene than 'Castlebrite' during ripening. Postharvest treatments with 1 ppm gaseous 1-methylcyclopropene (1-MCP) at 0°C for 24 h delayed softening of unripened 'Patterson' apricots during subsequent storage at 5°C for 14 days. Exposure to exogenous ethylene during cold storage antagonized the effect of 1-MCP treatment on fruit firmness. Flesh firmness was significantly higher on 'Patterson', but not 'Castlebrite', apricots stored at 5°C for 14 days with three 9-g potassium permanganate sachets per box than on apricots packed with none or one sachet per box. Neither 1-MCP treatment, ethylene exposure, nor packaging with sachets affected brown rot development during cold storage on apricots wound-inoculated with *Monilinia fructicola*. None of these postharvest treatments influenced apricot soluble solids concentration (SSC) or titratable acidity (TA).

INTRODUCTION

In a recent research work, we observed (Palou et al., 2002a) that among a variety of climacteric (peach, plum, nectarine, and apricot) and non-climacteric (sweet cherry) stone fruits, only apricots were adversely affected by continuous exposure to exogenous ethylene during cold storage. 'Patterson' and 'Castlebrite' apricots continuously exposed to 1, 10, or 100 ppm exogenous ethylene during 7 or 14 days of storage at 5°C were significantly softer than untreated apricots. Fruit internal quality attributes, such as soluble solids concentration (SSC) and titratable acidity (TA), were not affected by ethylene exposure. Similar detrimental effects of ethylene on apricot flesh firmness have also been reported by other researchers. Brecht et al. (1982) observed that a treatment with 100 ppm ethylene for 48 h at 20°C accelerated softening of apricots. Andrich and Fiorentini (1986) reported that controlled atmosphere conditions that inhibit ethylene production improved storage quality of apricots. Therefore, the commercial adoption of effective methods to protect harvested apricots against the deleterious effects of endogenous or exogenous ethylene should be considered.

Aminoethoxyvinylglycine (AVG) is an ethylene-biosynthesis inhibitor approved for field applications in pome fruit orchards. It is a growth regulator whose mode of action is the inhibition of ACC-synthase activity (Yu and Yang, 1979). When applied as a preharvest spray, it suppressed ethylene production in apples and significantly delayed fruit ripening (Williams, 1980). When applied as a postharvest dip treatment on peaches and nectarines, it reduced the rate of fruit softening (Byers, 1997; Garner et al., 2001).

1-methylcyclopropene (1-MCP) is an extensively studied ethylene-action inhibitor that has recently been shown to delay ripening and improve postharvest quality of a wide variety of fruits and vegetables, including pome fruits (Watkins et al., 2000), citrus and tropical fruits (Porat et al., 1999; Feng et al., 2000), strawberry (Jiang et al., 2001), and stone fruits (Fan et al., 2002) including apricots (Fan et al., 2000; Dong et al., 2002). It is

a cyclic olefin that blocks ethylene receptors and thus the ethylene-mediated ripening process (Sisler and Serek, 1997).

Among the large number of reagents and techniques that have been tested over the years to remove ethylene from the atmosphere of storage rooms when ventilation cannot be used, only potassium permanganate is presently in common commercial use. A number of commercial potassium permanganate scrubbers are available in sachets, filters, blankets, and other specialized trapping devices (Sherman, 1985).

The objective of this work was to evaluate the effects of postharvest treatments with AVG, 1-MCP, and potassium permanganate sachets on postharvest quality attributes of apricots. The influence of these treatments on the development of the most important postharvest disease of apricot, brown rot, caused by *Monilinia fructicola* (G. Wint.) Honey, was also investigated.

MATERIALS AND METHODS

Fruit

'Patterson' and 'Castlebrite' apricots (*Prunus armeniaca* L.) from the San Joaquin Valley (California, USA) were purchased from local packinghouses on their harvest dates and used in the experiments before any postharvest treatments were applied. Initial fruit quality was determined in the laboratory the same day of arrival as described below. Fruit for decay development assessment were organically grown. These fruit were superficially disinfected by immersion for 1 min in diluted bleach (0.5% sodium hypochlorite), rinsed with fresh water, and allowed to air dry at room temperature.

AVG Treatments

'Patterson' and 'Castlebrite' apricots were dipped for 1 min in aqueous solutions at room temperature ($20 \pm 2^\circ\text{C}$) containing 0 (control), 6.25, 12.5, 25, or 50 ppm (w/v) aminoethoxyvinylglycine hydrochloride (AVG, ReTain[®], Valent USA Corp., Fresno, CA, USA) and allowed to air dry. Treated fruit was held at 20°C and 95% RH for a 5-day ripening period.

Internal fruit quality [flesh firmness, SSC, and TA (percent of malic acid)] was determined at harvest and during the ripening period following the procedures described by Crisosto et al. (1993). Fruit firmness, SSC, and TA were determined using a U.C. Firmness Tester (7.9 mm tip), a handheld refractometer (Model ATC-1, Atago Co., Ltd., Tokyo, Japan), and an automatic titrator (Titration Manager TIM800, Titralab, Radiometer Analytical S.A., Villeurbanne Cedex-Lyon, France), respectively. Three 5-fruit replicates were used for each quality determination.

Ethylene produced by treated apricots was assessed daily during the ripening period according to Palou et al. (2002b). Three 1-fruit replicates per AVG concentration were used. Each apricot was weighed and placed in a 750 ml plastic container connected to an air flow-through system with a flow rate of $40 \text{ ml}\cdot\text{min}^{-1}$. Air samples were taken daily from each container with a plastic syringe and ethylene concentrations measured with a gas chromatograph equipped with a flame ionization detector (Carle AGC-211, EG&G Chandler Engineering, Tulsa, OK, USA). The experiment was repeated twice.

Fruit Inoculation

M. fructicola (isolate 79-1) was incubated at 20°C for 7 to 14 days on Petri dishes containing potato dextrose agar (PDA) medium. Spores were rubbed from the agar surface with a sterile glass rod after 5 ml of 0.05% (w/v) Triton X-100 in sterile water was added. This high-density spore suspension was passed through two layers of cheesecloth and, after counting the number of spores with a hemacytometer, diluted with sterile water to a suspension containing 2×10^4 spores ml^{-1} .

Organic apricots were placed on plastic cavity trays in 7.8-L polypropylene containers, wounded once on the equator of the fruit cheek with a stainless steel probe tip 1 mm wide by 2 mm in length, and inoculated, using a micropipet, with 20 μl of the spore

suspension. Each plastic container contained 15 apricots and paper towels on the bottom to maintain high relative humidity. An incubation period of 24 h at 20°C was allowed between fruit inoculation and treatment.

1-MCP Treatments

‘Patterson’ apricots were treated with 1 ppm (v/v) 1-MCP (Ethylbloc[®], Agrofresh Inc., Spring House, PA, USA) for 24 h at 0°C in a sealed 0.338 m³ aluminium tank. Treated and untreated (control) fruit were then placed in other 0.338 m³ water-sealed aluminium tanks, connected to an ethylene flow-through system and continuously exposed to 0 (air flow) or 1 ppm (v/v) exogenous ethylene during a 14-day storage period at 5°C. Flow rates and mixtures of compressed air and ethylene were established using a main mixing board and secondary flowboards with micrometering needle valves. Flow rates were set at 1.4 L·min⁻¹ and measured with a digital flowmeter (Model ADM-1000, J&W Scientific, Folsom, CA, USA). Fruit quality was determined weekly as previously described using three 10-fruit replicates per treatment.

‘Patterson’ apricots inoculated with *M. fructicola* were treated with 1-MCP and/or exogenous ethylene as described above. Brown rot incidence (number of decayed fruit) and severity (lesion size) were determined weekly on three 15-fruit replicates during storage at 5°C for 14 days. The experiment was repeated twice.

Potassium Permanganate Sachets

‘Patterson’ and ‘Castlebrite’ apricots were placed in plastic trays (36 fruit per tray, 1 tray per box) in commercial cardboard boxes (29.5 cm wide by 50.0 long cm by 10.0 cm high), packaged with 0 (control), one (in the center of the tray), or three (one in the center and one in each of the ends of the tray) potassium permanganate sachets per box, and stored at 5°C for 14 days. Each sachet (Power Pellets, Ethylene Control Inc., Selma, CA, USA) contained 9 g of potassium permanganate in pellets of 0.3-0.5 cm diameter. Fruit quality was determined weekly as previously described using three 10-fruit replicates per treatment.

Brown rot development was assessed weekly on three boxes (replicates) per treatment, each box containing 36 fruit previously inoculated with *M. fructicola*. In this case, decay severity was rated by using the following quantitative scale [adapted from Hong et al. (1998)]: 0, no symptoms; 1, the area exhibiting brown rot lesion restricted to < 1 cm diameter around the wound; 2, the lesion area extending beyond 1 cm in diameter but still not covering the whole fruit surface (top half) of the fruit; and 3, the lesion area covering the majority of the fruit surface. The experiment was repeated twice.

Statistical Analysis

Data on decay development and fruit quality were subjected to analysis of variance using SAS software (SAS Institute Inc., Cary, NC, USA). Data on incidence of brown rot were arcsine transformed. When appropriate, means were separated by Fisher’s Protected LSD test ($P = 0.05$).

RESULTS AND DISCUSSION

AVG Treatments

AVG-treated ‘Patterson’ apricots were significantly firmer than control fruit after 5 days of ripening at 20°C. Furthermore, fruit treated with 50 ppm AVG were firmer than fruit treated with 6.25, 12.5, or 25.0 ppm AVG (Fig. 1Aa). After 3 days of ripening at 20°C, but not after 5 days, ‘Castlebrite’ apricots treated with 50 ppm AVG were firmer than control fruit or fruit treated with other AVG concentrations (Fig. 1Ab). AVG dips had no effect on SSC or TA in any of the experiments (data not shown).

AVG-treated ‘Patterson’ apricots produced significantly less ethylene than control fruit after 4 and 5 days of ripening at 20°C. Production of ethylene was strongly inhibited on fruit treated with 25 or 50 ppm AVG (Fig. 1Ba). ‘Castlebrite’ apricots showed a

different pattern of ethylene production (Fig. 1Bb). Compared to 'Patterson', the ethylene production rate of 'Castlebrite' apricots was clearly higher after 1, 2, or 3 days of ripening, but lower after 4 or 5 days. AVG treatment did not influence the rate of ethylene production as much as in 'Patterson'. In general, AVG-treated fruit produced less ethylene after 4 or 5 days at 20°C than after 3 days (Fig. 1Bb).

These results implied a beneficial effect of postharvest AVG dips at relatively low concentrations on the storage life of apricots, especially on those cultivars that evolve higher amounts of ethylene. In previous work with 'Snow King' peach, a white flesh cultivar economically important in California, we observed that fruit dipped for 60 s in a 50-ppm AVG solution showed higher flesh firmness and lower ethylene production rate than control fruit during a 5-day ripening period at 20°C following a 5-day storage period at 0°C and a 18-day simulated shipment at 0°C (Garner et al., 2001). A similar reduction of ethylene production, delay of fruit softening, and no effect on internal quality (SSC and TA) were reported by Byers (1997) on 'Bisco' and 'Cresthaven' peaches and 'Redgold' nectarines submerged in AVG solutions. This author used higher AVG concentrations than we used (0, 167, 333, 666, and 2,664 ppm), and he observed that AVG treatment at 666 ppm or higher completely suppressed measurable ethylene evolution from fruit samples, even after being kept at room temperature for 12 days.

1-MCP Treatments

1-MCP treatment and continuous exposure to exogenous ethylene showed antagonistic effects on softening of 'Patterson' apricots during storage at 5°C. Fruit treated with 1-MCP and not exposed to ethylene were significantly firmer than the rest of the fruit (Fig. 2). No significant differences among treatments were found for SSC or TA (data not shown). Similarly, a significant influence of 1-MCP treatments on fruit firmness and ethylene production but not on SSC, TA, or skin color of 'Canino' apricots was reported by Dong et al. (2002). They observed that fruit maturity and time of treatment application significantly influenced the effects of postharvest 1-MCP treatments. Fan et al. (2000) found that the onset of ethylene production and fruit softening were delayed, and the respiration rate was reduced on 'Perfection' apricots treated with 1 ppm 1-MCP for 4 h at 20°C and then stored at 0 or 20°C. Likewise, the production of volatile alcohols and esters during ripening at 20°C was delayed on 1-MCP-treated fruit.

Neither 1-MCP treatment nor exposure to ethylene significantly affected brown rot incidence and severity during a 14-day storage period at 5°C (Fig. 3). This lack of influence of continuously applied exogenous ethylene on brown rot development during cold storage was also observed on artificially inoculated peaches, plums, nectarines, and cherries (Palou et al., 2002a). Apparently, the gas neither directly stimulated growth *in vivo* of *M. fructicola* nor induced in the fruit significant mechanisms of resistance against the pathogen. In tests *in vitro*, while germination and germ tube elongation of spores of *M. fructicola* were slightly stimulated by exposure to exogenous ethylene (1 or 10 ppm), the treatments had no influence on growth rate of the fungus on PDA at 20°C (El Kazzaz et al., 1983).

Potassium Permanganate Sachets

Fruit firmness was significantly higher on 'Patterson', but not 'Castlebrite', apricots stored at 5°C for 7 and 14 days with three 9-g potassium permanganate sachets per box than on apricots packed with none or one sachet per box (Table 1). Differences in the pattern of ethylene production may explain the different response obtained with 'Patterson' and 'Castlebrite' apricots. On both cultivars, the presence and amount of sachets had no effect on fruit SSC or TA (data not shown).

Storage with one or three sachets per box did not significantly affect brown rot incidence and severity on both 'Patterson' and 'Castlebrite' apricots wound-inoculated with *M. fructicola* and stored at 5°C for 14 days (Table 1). In a similar work with 'Flavorcrest' peaches, neither brown rot nor gray mold (caused by *Botrytis cinerea* Pers.:Fr.) development were influenced by the use of one or three potassium

permanganate sachets per box (Crisosto et al., 2000).

In summary, all AVG, 1-MCP, and 3-sachets treatment could be used to satisfactorily delay fruit softening and prolong the postharvest life of apricots. This delay could allow additional time for transport and marketing and may reduce physical damage to the fruit. However, as shown by our results and the work of others (Fan et al., 2000; Dong et al., 2002), the response to these treatments may vary with cultivar and maturity stage, treatment timing and characteristics, and storage environmental conditions after treatment. Particularly, the presence of exogenous ethylene during apricot storage or shipment could counteract the effect of these treatments.

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Tables

Table 1. Softening and brown rot development on apricots commercially packed with 0, 1, or 3 potassium permanganate sachets and stored at 5°C.

Cultivar	Treatment ¹	Cheek firmness (N)		Brown rot			
				Incidence ³ (%)		Severity (index)	
		7 ²	14	7	14	7	14
'Patterson'	0 sachets	10.2 a	3.1 a	0 a	60.0 a	0 a	0.8 a
	1 sachet	10.7 a	4.0 a	0 a	73.3 a	0 a	1.0 a
	3 sachets	16.9 b	8.0 b	0 a	54.6 a	0 a	0.7 a
'Castlebrite'	0 sachets	16.4 a	8.4 a	0 a	65.7 a	0 a	2.0 a
	1 sachet	20.5 a	10.2 a	0 a	63.8 a	0 a	2.2 a
	3 sachets	20.9 a	10.2 a	0 a	64.8 a	0 a	2.1 a

¹ For each cultivar, values within columns followed by unlike letters are different according to Fisher's Protected LSD test ($P = 0.05$).

² Days of storage at 5°C.

³ Incidence data were transformed to the arcsine of the square root of the proportion of infected fruits before the analysis of variance. Non-transformed data are shown.

Figures

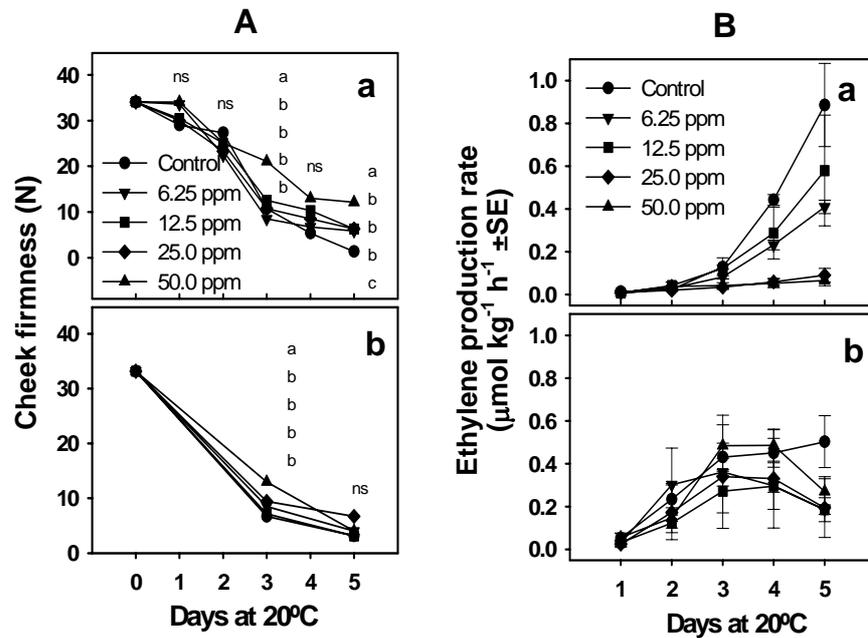


Fig 1. Softening (A) and ethylene production rate (B) of ‘Patterson’ (a) and ‘Castlebrite’ (b) apricots during a 5-day ripening period at 20°C following 1 min AVG dips.

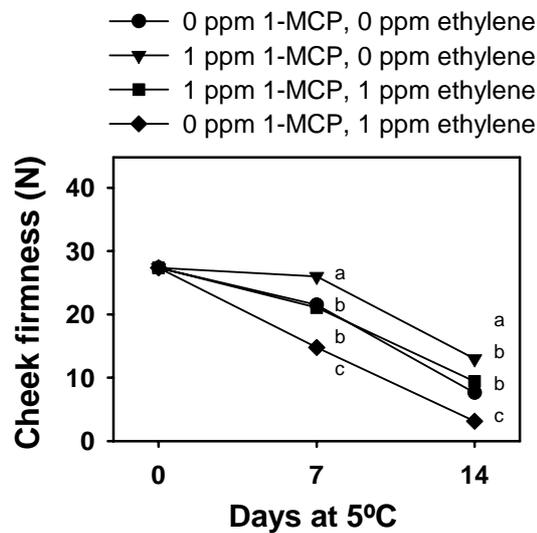


Fig. 2. Softening of ‘Patterson’ apricots treated with 0 or 1 ppm 1-MCP and exposed to 0 or 1 ppm ethylene during storage at 5°C.

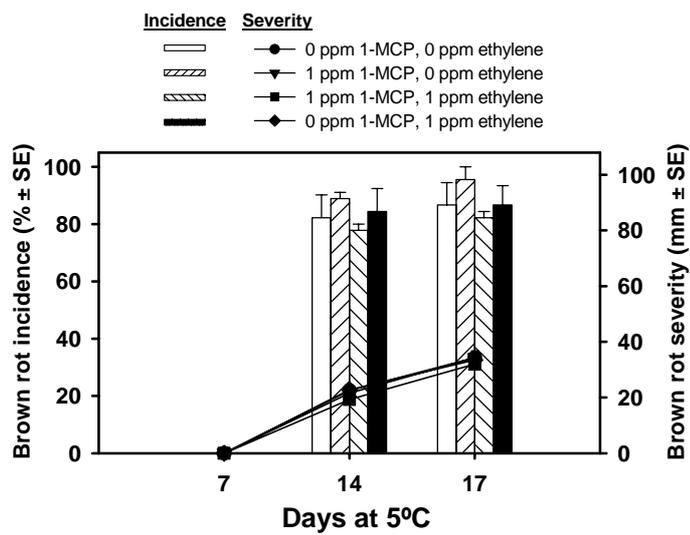


Fig. 3. Brown rot incidence and severity on 'Patterson' apricots wounded inoculated with *Monilinia fructicola*, treated with 0 or 1 ppm 1-MCP and exposed to 0 or 1 ppm ethylene during storage at 5°C.