ReTain™ Affects Maturity and Ripening of ‘Bartlett’ Pear

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Abstract. ReTain™, a commercial derivative of aminoethoxyvinylglycine, was applied as a single application at 124 g·ha⁻¹ a.i. to ‘Bartlett’ pear (*Pyrus communis* L.) trees 28, 21, 14, or 7 days prior to initial commercial harvest and at 62 g·ha⁻¹ a.i. in combination with naphthaleneacetic acid (NAA) at 92 g·ha⁻¹ a.i. 14 days prior to initial commercial harvest. Maturity and quality of treated fruits at harvest and following storage were compared with those of nontreated pears in 1996 and 1997. Ethylene production by mature green pears at harvest was not significantly affected by ReTain™ treatments, although softening, loss of chlorophyll, and starch clearance were usually inhibited by the 14- or 7-day treatment. ReTain™ suppressed ethylene production, softening and loss of chlorophyll in ripening pears and mature green pears cold-stored for 4 months, although loss of chlorophyll did not differ in the cold-stored fruit in 1997. ReTain™ had little effect on softening during a ripening period of 6 days after 4 months of cold storage. Application at 14 or 7 days prior to initial harvest appeared most effective, often with little difference between the two timings, and the 28- or 21-day treatment or combined ReTain™ and NAA treatment were seldom more effective. ReTain™ applied 14 or 7 days before initial harvest delayed fruit maturation by 4–10 days depending on the maturity index. The maturity or ripeness of pears from the combined ReTain™ and NAA, NAA only, and control treatments was often similar or differed only slightly. Premature ripening, prevalent in 1997, was dramatically suppressed in fruit treated with ReTain™. Ripening of both ReTain™- and non-ReTain™-treated fruit with ethylene reduced premature ripening by ≈50%.

ReTain™ (Abbott Laboratories, North Chicago) is a commercial product containing the plant growth regulator aminoethoxyvinylglycine (AVG) and has recently received registration for use on apples (*Malus domestica* Borkh.) and pears in California and Washington. Yang and Hoffman (1984) reported that AVG suppressed ethylene biosynthesis by inhibiting enzymatic activity responsible for the conversion of S-adenosyl methionine to 1-aminocyclopropane-1-carboxylic acid.

Inhibition of ethylene production by preharvest AVG treatment has been documented in apple fruit (Autio and Bramlage, 1982; Bangerth, 1978; Bramlage et al., 1980; Child et al., 1984; Chu et al., 1981; Halder-Doll and Bangerth, 1987; Kondo and Hayata, 1995; Shafer et al., 1997; Watkins et al., 1998). However, the reports have varied as to the effects of AVG on the maturity and ripening indices of flesh firmness, skin color, starch and titratable acidity. Bramlage et al. (1980) found that the magnitude of delayed ripening in apple was dependent on cultivar and AVG concentration. Chun et al. (1997) contended that the timing of application influenced preharvest drop of ‘Tsugaru’ apples much more than did concentration. The effects of AVG on pears are less well documented.

Preharvest AVG treatment suppressed ethylene production and delayed the respiratory climacteric (Romani et al., 1982), and delayed degreening (Romani et al., 1983) in ‘Bartlett’ fruit held at 20 °C. Wang and Mellenthin (1977) found that postharvest AVG treatment inhibited ethylene production in both ‘Anjou’ and ‘Bartlett’, although retention of flesh firmness and malic acid content occurred only in ‘Anjou’. A similar study reported that postharvest AVG treatment of ‘Bartlett’ suppressed ethylene production and fruit respiration and delayed flesh firmness loss and yellowing (Ness and Romani, 1980).

Suppressing ethylene production in ‘Bartlett’ pears may increase yields by reducing premature fruit abscission, and indirectly increase fruit size by delaying harvest of slower-maturing fruit. ‘Bartlett’ growers often utilize the synthetic auxin, naphthaleneacetic acid (NAA), which can suppress preharvest fruit abscission, but can also result in fruit softening. Delaying harvest may provide flexibility for scheduling of labor, fruit processing and packaging, cold storage, and marketing. Reducing fruit ethylene production may reduce the incidence of premature ripening on the tree, enhance the storage life, and reduce the rate of ripening of ‘Bartlett’ pears.

A commercial-scale study using ReTain™ was undertaken to further investigate the effects of AVG on maturation, ripening and storage life of ‘Bartlett’ pear fruit. The study compared various preharvest application timings of ReTain™ applied at the maximum label rate of 124 g·ha⁻¹ a.i. (1.77 oz/acre a.i.)

and at half the maximum label rate in conjunction with NAA, to nontreated fruit and to fruit treated with NAA.

Materials and Methods

Experimental design. Fruit were obtained from mature, uniformly cropped ‘Bartlett’ trees growing in a commercial orchard in Mendocino County, Calif. in both 1996 and 1997. The experiment consisted of a randomized complete-block design featuring six treatments (Table 1) replicated across four blocks. The NAA (Amvac Chemical Corp., Newport Beach, Calif.) was applied 25 d prior to initial commercial harvest in 1996 and 14 d prior to initial harvest in 1997. ReTain™ at 62 g·ha⁻¹ (0.89 oz/acre) (one-half label rate) was applied with NAA in 1997, in place of the ReTain™ application, 28 d prior to initial commercial harvest. All concentrations are expressed as a.i. The treatments were applied with an organo-silicon surfactant (0.1% v/v Silwet L77; Union Carbide Corp., Danbury, Conn.) in water with a commercial spray unit at a rate of 935 L·ha⁻¹ (100 gal/acre).

Fruit maturity at harvest. In 1996, fruit were harvested twice, 14 d apart (Table 1). The following year there were three harvests, with the second and third harvests 12 and 21 d after the first. The first harvest each year coincided with the initial commercial harvest. At each harvest, representative pears from three trees within each treatment plot were collected from previously nonharvested trees. Blemished fruit were removed. Forty fruit were selected randomly from each treatment (10 fruit/treatment plot) and evaluated for skin hue color (°) at opposite sides at the equator of each fruit using colorimetry (model CR-300; Minolta, Ramsey, N.J.). Flesh firmness (N) at opposite sides at the equator of each fruit (skin removed) was determined using a penetrometer (Ametek, Hatfield, Pa.) fitted with an industry-standard 8-mm diameter probe. Fruit were then assessed for total soluble solids content (SS) by refractometry (Abbe model 10450; American Optical, Buffalo, N.Y.) and titratable acidity (TA, malic acid equivalents) by automatic titration (PHM85 Precision, ABU80; Radiometer, Copenhagen, Denmark) using the juice from

Table 1. Application rate and timing of ReTain™ and NAA treatments of ‘Bartlett’ pears.

Treatment (g·ha ⁻¹ a.i.)	Time of treatment (d prior to initial commercial harvest ^a)	
	1996 ^b	1997 ^c
Control	---	---
NAA, 92	25	14
ReTain™, 124	7	7
	14	14
	21	21
	28	---
ReTain™, 62 + NAA, 92	---	14

^aCommencement of commercial harvest regulated by industry-set standards based on mean pear firmness and soluble solids within the orchard.

^bHarvest dates: 29 July 1996 (initial) and 12 Aug 1996; 23 July 1997 (initial), 4 and 13 Aug. 1997.

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a wedge of each pear. Fruit starch clearance (%) was estimated from a transverse section of each pear following iodine/potassium iodide staining for 2 min. Ethylene production ($\mu\text{L}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$) was measured by sampling the headspace of closed jars containing an additional sample of 16 pears from each treatment (four fruit/treatment plot) by flame ionization detection (Carle Analytical Gas Chromatograph model 211; Carle, Tulsa, Okla.).

Fruit ripening at harvest. In 1996, a sample of 60 fruit from each treatment (15 fruit/treatment plot) of each harvest was treated with ethylene at $100\ \mu\text{L}\cdot\text{L}^{-1}$ during the initial 24 h of ripening at $20\ ^\circ\text{C}$. The fruit were evaluated for flesh firmness and skin color (visual assessment) after an additional 5 d at $20\ ^\circ\text{C}$. In 1997, two samples of 60 fruit from each treatment were ripened with or without an initial 24-h ethylene treatment followed by an additional 5 d at $20\ ^\circ\text{C}$, and evaluated for firmness, color, and premature ripening. Ethylene production from 16 fruit of each treatment (non-ethylene-treated) was measured, as described above, after ripening at $20\ ^\circ\text{C}$ for 6 (1997) or 7 (1996) d.

Fruit storage. In both seasons, two 80-fruit samples of pears from each treatment (20 fruit/treatment plot) at each harvest, were stored at $-1\ ^\circ\text{C}$ for 4 months. Upon removal from cold storage, one sample of fruit was immediately evaluated for flesh firmness, skin color, SS, TA, and storage scald. In 1997, ethylene production was measured, as described above, from a subsample of 16 pears from each treatment after 1 d at $20\ ^\circ\text{C}$. The second sample of fruit from each treatment was ripened at $20\ ^\circ\text{C}$ for 5 d and evaluated for flesh firmness, skin color, storage scald, and core breakdown.

Data analysis. The maturity or ripening indices of fruit at harvest, ripened immediately after harvest, immediately following cold storage, and ripened after cold storage for each year were analyzed independently by analysis of variance. Treatment, harvest, and block main effects were tested within each analysis. Duncan's multiple range test was utilized for mean separation of treatment and harvest. Interaction of treatment with harvest was also tested.

Results

Fruit maturity. Ethylene production immediately following harvest from pears of harvest 1 and 2 was very low in all treatments, particularly in fruit from 1996 (Table 2), and the effects of ReTainTM were nonsignificant in both years of the study. Fruit harvested at late maturity (13 Aug.) produced more ethylene than did those harvested at the initial commercial harvest date or 12 d later in 1997. Flesh firmness (1996), SS, and TA did not differ between treatments, but significant treatment effects were detected for the remaining indices. In 1997, the 7-d ReTainTM-treated fruit were over 2 N firmer than fruit from the remaining treatments, and fruit treated with ReTainTM + NAA were softer than the remaining ReTainTM-treated and con-

Table 2. Effects of ReTainTM on the maturity indices of 'Bartlett' pears at harvest in 1996 and 1997.

		Ethylene prod. ($\mu\text{L}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$)	Firmness (N)	Skin hue color ($^\circ$) ^z	Starch clearance (%) ^y	SS (%)	TA (%)
1996							
Treatment							
ReTain TM	7 d ^x	0.002	68.1	113.33 a ^w	31 b	10.9	0.23
	14 d	0.004	68.1	113.58 a	24 b	11.0	0.24
	21 d	0.002	67.6	113.34 a	25 b	10.9	0.23
	28 d	0.001	70.8	113.26 ab	24 b	10.8	0.23
NAA	25 d	0.002	67.6	113.27 ab	27 b	10.9	0.23
Control		0.005	65.9	112.87 b	42 a	10.9	0.25
Harvest							
1		0.003	72.1 a	114.12 a	24 b	10.7 b	0.24 a
2		0.003	64.1 b	112.44 b	34 a	11.1 a	0.23 b
Significance							
Treatment (T)		NS	NS	*	**	NS	NS
Harvest (H)		NS	***	***	***	**	*
Block		NS	NS	NS	NS	NS	*
T $\times$ H		NS	NS	NS	NS	NS	NS
1997							
Treatment							
ReTain TM	7 d	0.102	71.6 a	112.81 a	9 bc	11.6	0.29
	14 d	0.086	69.0 b	112.35 ab	7 c	11.6	0.28
	21 d	0.098	68.5 b	112.11 b	11 bc	11.6	0.27
Ret + NAA	14 d	0.199	65.9 c	112.11 b	15 ab	11.6	0.30
NAA	14 d	0.231	66.3 bc	112.11 b	17 a	11.5	0.28
Control		0.281	69.0 b	111.94 b	12 abc	11.6	0.29
Harvest							
1		0.015 b	74.3 a	113.43 a	5 c	10.9 c	0.30 a
2		0.037 b	68.5 b	112.37 b	10 b	11.7 b	0.28 b
3		0.401 a	62.3 c	110.92 c	20 a	12.1 a	0.28 b
Significance							
Treatment (T)		NS	***	*	**	NS	NS
Harvest (H)		***	***	***	***	***	**
Block		NS	NS	NS	NS	NS	NS
T $\times$ H		NS	NS	NS	NS	NS	NS

^zAngle attributed to colors classed as red (0°), yellow (90°), green (180°), blue (270°) or an intermediate between any adjacent pair of these colors.

^yProportion of the surface of a transverse section of fruit clear of starch staining. Data was angular transformed prior to analysis.

^xDays prior to initial harvest that treatment was applied.

^wMean separation within columns and factors by DMRT, $P \leq 0.05$.

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

trol pears by more than 2.5 N (Table 2). Further evidence of delayed maturation by ReTainTM in 1997 was indicated by greener skin color in the 7-d treatment compared with NAA-treated and control fruit. In 1996, the fruits treated with ReTainTM at 21 and 14 d were greener than control fruit but not NAA-treated fruit. Starch clearance was more advanced in control fruit than in treated fruit in 1996, but differences in starch content among the remaining treatments were nonsignificant. Starch clearance in 1997 was, in general, much less than in 1996, with starch levels differing less among treatments. However, starch hydrolysis was suppressed more in 21-, 14-, and 7-d ReTainTM-treated than in NAA-treated pears. Starch loss in ReTainTM + NAA-treated fruit was relatively advanced, but differed significantly only from that of fruits in the 14-d ReTainTM treatment.

Fruit ripening at harvest. ReTainTM suppressed ethylene production in ripened pears in both years, while NAA did not (Table 3). ReTainTM-treated fruit ripened without ethylene were 11–20 N firmer and were greener than the control, NAA-, and ReTainTM + NAA-

treated fruit (Table 3). Firmness of NAA-treated pears was similar to that of control and ReTainTM + NAA-treated fruit, but they were yellower. ReTainTM-treated fruit from the second harvest were ≈ 26 N firmer than non-ReTainTM-treated fruit (Fig. 1A), resulting in an interaction of treatment and harvest. Similarly for skin color, a treatment and harvest interaction occurred with ReTainTM being more effective at maintaining green skin in fruit from harvest 2 (data not shown).

Firmness loss and yellowing of ethylene-ripened fruit was also suppressed by ReTainTM treatment despite smaller differences among treatments (Table 3). NAA-treated fruit were similar in firmness and color to control and ReTainTM + NAA-treated fruit. For harvest 1, ReTainTM-treated fruit averaged > 9 N firmer than non-ReTainTM-treated fruit, while harvest 2 and 3 ReTainTM-treated fruit averaged only 2 N firmer (Fig. 1B). Treatment effects on skin color in harvest 3 fruit were also small compared with those in harvest 1 and 2 fruit (data not shown).

Premature ripening was observed predominantly in fruit from harvest 3 in 1997,

Table 3. Effects of ReTain™ on 'Bartlett' pears ripened immediately after harvest at 20 °C for 6 d with or without an initial 24-h ethylene treatment.

		No ethylene			Ethylene	
		Ethylene prod. ($\mu\text{L}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$)	Firmness (N)	Skin color score ²	Firmness (N)	Skin color score ²
1996						
Treatment						
ReTain™	7 d ³	1.77 b ^a	---	---	18.7 a	2.5 c
	14 d	1.60 b	---	---	17.8 a	2.7 bc
	21 d	2.56 b	---	---	16.0 b	2.7 bc
	28 d	2.23 b	---	---	16.0 b	2.7 bc
NAA	25 d	3.80 a	---	---	14.7 c	2.9 ab
Control		4.37 a	---	---	14.7 c	3.0 a
Harvest						
1		2.76	---	---	16.9 a	2.5 b
2		2.68	---	---	16.0 b	3.0 a
Significance						
Treatment (T)		***			***	*
Harvest (H)		NS			**	***
Block		NS			NS	NS
T × H		NS			NS	NS
1997						
Treatment						
ReTain™	7 d	9.1 c	49.8 a	1.8 e	19.1 ab	2.8 b
	14 d	4.8 d	50.7 a	1.9 de	20.5 a	2.6 c
	21 d	9.7 c	44.5 b	2.0 cd	17.4 bc	2.8 b
Ret + NAA	14 d	13.4 bc	35.6 bc	2.2 bc	14.2 d	3.1 a
NAA	14 d	17.2 a	30.3 c	2.6 a	14.2 d	3.1 a
Control		18.5 a	32.9 c	2.3 b	16.0 cd	3.1 a
Harvest						
1		5.3 c	65.0 a	1.3 c	20.9 a	2.1 c
2		12.5 b	34.7 b	2.1 b	16.9 b	2.8 b
3		18.6 a	19.1 c	3.1 a	13.4 c	3.9 a
Significance						
Treatment (T)		***	***	***	***	***
Harvest (H)		***	***	***	***	***
Block		NS	*	***	NS	*
T × H		NS	**	*	***	***

²Skin color score: 1 = green, 2 = light green, 3 = light yellow, 4 = yellow.

³Days prior to initial harvest that treatment was applied.

^aMean separation within columns and factors by DMRT, $P \leq 0.05$.

ns, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

where 22% to 33% of non-ReTain™-treated fruit ripened without ethylene were affected. Only 2% to 8% of ReTain™-treated fruit showed symptoms of premature ripening (Fig. 2). For pears ripened with ethylene, 8% to 18% of non-ReTain™- and 0% to 3% of ReTain™-treated fruit, respectively, ripened prematurely. In harvest 2 fruit, a lower incidence of premature ripening (5% to 11%) occurred in non-ethylene-ripened pears that were not treated with ReTain™. Premature ripening was not detected in samples of this fruit that were ripened with ethylene.

Fruit storage. Following storage at $-1\text{ }^{\circ}\text{C}$ for 4 months and $20\text{ }^{\circ}\text{C}$ for 1 d, fruit ethylene production was 350-fold as great as that of pears evaluated immediately after harvest (1997). Despite this dramatic increase, pears treated with ReTain™ 7 d prior to initial harvest produced less ethylene than did control or NAA-treated fruit, and production was similar to that of the 14-d ReTain™- or 14-d ReTain™ + NAA-treated fruit (Table 4). Although ethylene production immediately after harvest increased as harvest was delayed (Table 2), production by stored fruit decreased

from harvest 1 to 3. ReTain™-treated pears were firmer than control fruit by more than 2 and 4 N in 1996 and 1997, respectively (Table 4). Timing of ReTain™ application did not affect firmness. NAA-treated fruit were softer than ReTain™-treated fruit only in 1997. Firmness of ReTain™ + NAA-treated fruit was similar to that of NAA and control fruit. In 1996, fruit skin color was greener in the 14- and 7-d ReTain™ treatments than in the NAA and control treatments, but the other ReTain™ treatments did not affect color. In 1997, after 4 months of cold storage, overall skin color was not affected by treatments except in harvest 1, when the ReTain™-treated pears

were not as yellow (data not shown), resulting in an interaction between treatment and harvest. ReTain™ was less effective at maintaining flesh firmness in harvest 2 fruit than in harvest 1 and 3 fruit (Fig. 3A). Ethylene production after storage was suppressed only in harvest 1 fruit treated with ReTain™ within 14 d of the initial harvest (Fig. 3B).

Superficial scald incidence was similar among treatments in 1996, but was slightly higher in control fruit in 1997 (Table 4). In both years, scald incidence was greater in later harvested fruit. Soluble solids content was not affected by any treatment in 1996, or by ReTain™ + NAA, or 14- and 7-d ReTain™

Fig. 1. Flesh firmness of 'Bartlett' pears ripened at $20\text{ }^{\circ}\text{C}$ for 6 d (A) without or (B) with an initial 24-h exposure to ethylene in 1997. Timing of treatment application prior to initial harvest (23 July) for the 7-d ReTain™, 14-d ReTain™, 21-d ReTain™, 14-d ReTain™ + NAA, 14-d NAA, and control treatments is indicated in days. The vertical lines represent standard errors. Note difference in scale for A and B.

Fig. 2. Percentage of incidence of premature ripening in 'Bartlett' pears from harvest 3 in 1997 ripened immediately after harvest for 7-d ReTain™, 14-d ReTain™, 21-d ReTain™, 14-d ReTain™ + NAA, 14-d NAA, and control treatments. Timing of treatment application prior to initial harvest (23 July) is indicated above in days. The vertical lines represent SE.

Table 4. Effects of ReTain™ on maturity indices and superficial scald of nonripened 'Bartlett' pears held at -1 °C for 4 months and on ethylene production after an additional d at 20 °C.

		Ethylene prod. ($\mu\text{L}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$)	Firmness (N)	Skin hue color (°) ^z	Storage scald (%) ^y	SS (%)	TA (%)
1996							
Treatment							
ReTain™	7 d ^x	---	71.6 a	104.36 a ^w	4	11.6	0.16 bc
	14 d	---	73.0 a	104.22 a	2	11.8	0.17 b
	21 d	---	71.6 a	103.57 ab	6	11.6	0.15 c
	28 d	---	71.2 a	103.23 ab	3	11.7	0.15 c
NAA	25 d	---	71.6 a	102.82 b	5	11.7	0.15 c
Control		---	69.0 b	102.39 b	4	11.7	0.18 a
Harvest							
1		---	75.7 a	104.84 a	0 b	11.7	0.17 a
2		---	66.6 b	102.02 b	8 a	11.7	0.15 b
Significance							
Treatment (T)		**	*	NS	NS	***	
Harvest (H)		***	***	***	NS	***	
Block		NS	NS	NS	**	NS	
T × H		NS	NS	NS	NS	*	
1997							
Treatment							
ReTain™	7 d	83.0 c	68.1 a	101.21	6 b	12.5 bc	0.18
	14 d	95.5 abc	67.6 a	100.54	5 b	12.7 ab	0.18
	21 d	101.9 a	67.2 a	101.74	6 b	12.9 a	0.19
Ret + NAA	14 d	88.3 bc	65.0 b	101.84	6 b	12.5 bc	0.18
NAA	14 d	96.4 ab	62.7 b	100.47	6 b	12.4 c	0.18
Control		101.2 ab	63.2 b	100.28	9 a	12.7 ab	0.17
Harvest							
1		117.4 a	72.1 a	104.06 a	1 c	12.5 b	0.19 a
2		94.8 b	66.3 b	100.96 b	6 b	12.6 ab	0.18 b
3		70.9 c	58.3 c	98.02 c	12 a	12.7 a	0.17 b
Significance							
Treatment (T)		*	***	NS	*	*	NS
Harvest (H)		***	***	***	***	*	***
Block		NS	NS	NS	NS	NS	NS
T × H		*	***	***	NS	NS	NS

^zAngle attributed to colors classed as red (0°), yellow (90°), green (180°), blue (270°) or an intermediate between any adjacent pair of these colors.

^yProportion of fruit surface affected. Data was angular transformed prior to analysis.

^xDays prior to initial harvest that treatment was applied.

^wMean separation within columns and factors by DMRT, $P \leq 0.05$.

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

treatments in 1997. NAA-treated pears had lower SS than control or 21- and 14-d ReTain™-treated fruit in 1997. In 1996, TA was highest in control fruit followed by the 14-d ReTain™ treatment; the remaining treatments did not differ significantly. TA was similar for all treatments in 1997.

Fruit ripening after cold storage. Following 4 months of cold storage at -1 °C plus 5 d of ripening at 20 °C, fruit firmness differences between the 7-d ReTain™-treated fruit and the control and ReTain™ + NAA-treated fruit were significant only in 1997 (Table 5). Pears from the latter two treatments were almost 2 N softer than 7-d ReTain™-treated fruit. Pears treated with ReTain™ within 21 d of initial harvest were greener than control (both years) and NAA-treated fruit (1997 only) after ripening. Skin color of NAA- and 28-d ReTain™-treated fruit was similar to that of control fruit. For flesh firmness and skin color, differences between the ReTain™ and non-ReTain™ treatments were smaller in pears from harvest 2 than in those of the remaining harvests (data not shown), resulting in treatment × harvest interactions (Table 5). Superficial scald incidence was similar among treatments, but fruit

harvested later in the season were more susceptible to scald than were early-harvested fruit (Table 5). Similarly, core breakdown was more prevalent in harvest 3 fruit (1997) than in either of the earlier harvests, and in control fruit than in fruit treated with ReTain™ 21 d prior to initial harvest.

Estimation of delayed maturation by ReTain™. The delay in maturity of pears treated with ReTain™ was estimated by interpolating harvest delays that were based on the corresponding maturity or ripeness status of treated and nontreated fruit. The three harvests in 1997 provided greater reliability for estimating the delay in fruit maturation and only these results were utilized. Flesh firmness, skin color, and starch content were used as indicators for estimating the maturity delay, as the effects of ReTain™ on ethylene production, SS, and TA at harvest were nonsignificant (Table 2). A delay of ≈4 d in maturity of 14- and 7-d ReTain™-treated fruit was estimated from the relatively linear reduction in firmness of control fruit from harvest 1 to 3 (Fig. 4A). Pears from harvest 2 were harvested 12 d after harvest 1; the higher firmness of 14- and 7-d ReTain™-treated pears would be comparable

to nontreated fruit on d 8, representing a 4-d delay in maturation. A similar delay occurred at harvest 3. The delay in skin degreening and starch clearance in harvest 2 fruit was more dramatic and was interpolated at 6 to 7 d (Fig. 4B) and 7 to 10 d (Fig. 4C), respectively. The delay in maturity of 21-d ReTain™-treated fruit was ≈2 d with respect to skin color, and minimal with respect to firmness and starch clearance.

Discussion

'Bartlett' pears from all treatments were preclimacteric at harvest and ethylene production was similar among treatments. Ethylene production at harvest was higher in 1997 than in 1996. Average daily maximum and minimum temperatures for the month prior to harvest were over 2 °C lower in 1997 than in 1996, and the cooler weather during 1997 may have induced ethylene production prior to harvest (Wang et al., 1971). After 4 months of cold storage, ethylene production was reduced by treatment with ReTain™ 7 d prior to initial harvest. A single application of ReTain™ 7 to 28 d prior to initial harvest suppressed ethylene production in ripened pears, in agreement with findings from other researchers who used two applications of AVG at ≈3-fold higher concentration 14 and 42 d (Romani et al., 1982) or 14 and 28 d (Romani et al., 1983) before harvest. ReTain™ applied at one-half concentration in conjunction with NAA was less effective at reducing ethylene production of ripened fruit than was ReTain™ applied alone at full rates. Whether the reduced effect on ethylene production was due solely to the reduced concentration of ReTain™ or to an interaction between ReTain™ and NAA is not known. NAA-treated and control fruit produced similar levels of ethylene whether stored or nonstored, ripe or unripe.

In general, suppressed advancement of fruit maturity and ripening indices such as flesh softening, skin yellowing, and starch clearance in ReTain™-treated fruit was related to the reduction in ethylene production. Despite the lack of detectable effects of ReTain™ on ethylene production at harvest, fruit maturation was delayed, as indicated by greener skin, firmer flesh, and, in 1996, greater starch content, particularly in fruit treated with ReTain™ 14 or 7 d prior to initial harvest. Furthermore, ReTain™-treated fruit maintained slightly higher firmness and greener skin following 4 months of cold storage, with the magnitude of the effects relatively similar to the differences between ReTain™-treated and nontreated fruit at harvest. Although not tested here, the effects of ReTain™ on quality of pears cold-stored for <4 months may have been greater.

The residual effects of ReTain™ on suppressing softening and color change during ripening were more dramatic in 'Bartlett' pears ripened immediately after harvest at 20 °C without added ethylene (Table 3). Canneries and retailers would need to be aware of delayed ripening in freshly harvested ReTain™-treated fruit in order not to disrupt fruit ripening schedules. Benefits of

Fig. 3. (A) Flesh firmness and (B) ethylene production in nonripened 'Bartlett' pears after storage at -1°C for 4 months in 1997. Timing of treatment application prior to initial harvest (23 July) for the 7-d ReTainTM, 14-d ReTainTM, 21-d ReTainTM, 14-d ReTainTM + NAA, 14-d NAA, and control treatments is indicated in days. The vertical lines represent SE.

delayed ripening may be realized when this fruit is transported or held in facilities lacking cold storage, such as found in some foreign markets. However, ethylene treatment during ripening or cold storage prior to ripening severely limited or eliminated the effect of ReTainTM on ripening. Treatment differences for firmness and color of fruit ripened with ethylene or prior cold storage (Tables 3 and 5) were smaller than for fruit ripened without ethylene treatment or cold storage (Table 3), and similar in scale to existing treatment differences at harvest prior to ripening (Table 2). These findings are supported by reports from Romani et al. (1982) that prolonged cold storage counteracted ripening resistance in 'Bartlett' pears treated with AVG prior to harvest, and from Ness and Romani (1980) that ethylene treatment overcame ripening inhibition in 'Bartlett' pears previously treated with AVG after harvest. Other studies have reported that inhibition of ripening in apple by AVG can also be overcome by cold storage (Bramlage et al., 1980) and ethylene treatment (Autio and Bramlage, 1982).

While evidence from this study suggested that ReTainTM applied 28 or 21 d prior to initial harvest often inhibited fruit maturation or ripening, the delay was usually less than that experienced by fruit treated with ReTainTM 14 or 7 d prior to initial harvest. Other researchers have quantified the delay in ripening of 'Bartlett' pears treated with AVG before harvest by comparing the time after harvest required for treated and nontreated fruit to

reach the respiratory climacteric (Romani et al., 1982, 1983). Possibly of greater commercial interest to producers of 'Bartlett' pears is the delay in preharvest maturation of ReTainTM- or AVG-treated fruit. In this study, the delayed maturation at harvest due to ReTainTM was estimated by comparing flesh firmness, skin color, or starch content of treated and nontreated fruit. Based on skin color and starch content, ReTainTM application at 14 or 7 d prior to initial harvest delayed fruit maturation 6 to 10 d. These timings were less effective on fruit firmness, delaying softening ≈ 4 d. ReTainTM applied 21 d prior to initial harvest was less effective at delaying maturity than the 14- or 7-d timings. Its effects on fruit firmness and starch content were negligible, but it inhibited skin color by ≈ 2 d.

Cool preharvest temperatures stimulate early ethylene production and premature ripening in 'Bartlett' pears (Wang et al., 1971). ReTainTM probably reduced premature ripening by suppressing ethylene production, and

would potentially be a valuable tool to reduce fruit losses during cool harvest seasons. The reason for lower premature ripening in fruit ripened with ethylene gas is unknown, but warrants further investigation.

We conclude that ReTainTM applied at 124 g·ha⁻¹ a.i. 14 or 7 d prior to initial commercial harvest delayed fruit maturation by ≈ 7 d (4 to 10 d depending on maturity index). This fruit remained firmer and greener following 4 months of cold storage. Resistance to ripening occurred in freshly harvested ReTainTM-treated pears, but was counteracted by exposure of the fruit to ethylene during the ripening period after harvest, or by 4 months of cold storage.

The current label for ReTainTM allows for application 4 or more weeks before harvest. With a 7-d delay in fruit maturation and therefore a 7-d delay in harvest, the latest that ReTainTM could be applied, based on the current label, would be 3 weeks before the start of harvest for nontreated fruit. Our data indicate that ReTainTM would need to be

Table 5. Effects of ReTainTM on ripening and physiological disorders of 'Bartlett' pears following storage at -1°C for 4 months plus ripening at 20°C for 5 d.

		Firmness (N)	Skin hue color ($^{\circ}$) ^a	Storage scald (%) ^b	Core breakdown score ^c
1996					
Treatment					
ReTain TM	7 d ^w	17.4	95.19 a ^v	31	---
	14 d	16.9	95.53 a	32	---
	21 d	16.9	95.17 a	36	---
	28 d	16.5	94.52 ab	35	---
NAA, Control	25 d	16.0	94.46 ab	34	---
Harvest					
1		16.5	95.48 a	23 b	---
2		16.9	93.86 b	46 a	---
Significance					
Treatment (T)		NS	*	NS	
Harvest (H)		NS	***	***	
Block		NS	NS	NS	
T × H		NS	NS	NS	
1997					
Treatment					
ReTain TM	7 d	22.3 a	92.12 a	39	0.2 ab
	14 d	21.8 ab	92.03 a	37	0.3 ab
	21 d	20.9 ab	92.30 a	41	0.0 b
Ret + NAA	14 d	20.5 b	91.55 ab	44	0.2 ab
NAA	14 d	20.9 ab	90.97 bc	44	0.2 ab
Control		20.5 b	90.69 c	39	0.4 a
Harvest					
1		20.5	91.77	20 c	0.0 b
2		21.4	91.65	46 b	0.1 b
3		21.4	91.39	57 a	0.6 a
Significance					
Treatment (T)		*	***	NS	*
Harvest (H)		NS	NS	***	***
Block		NS	NS	NS	NS
T × H		*	***	NS	*

^aAngle attributed to colors classed as red (0°), yellow (90°), green (180°), blue (270°) or an intermediate between any adjacent pair of these colors.

^bProportion of fruit surface affected. Data was angular transformed prior to analysis.

^cIncidence of disorder: 0 = none, 1 = very minor, 2 = minor, 3 = moderate, 4 = severe.

^wDays prior to initial harvest that treatment was applied.

^vMean separation within columns and factors by DMRT, $P \leq 0.05$.

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

Fig. 4. Advancement of maturity indices in freshly harvested, mature green 'Bartlett' pears in 1997. Harvests 1, 2, and 3 occurred on day 0, 12, and 21, respectively. The estimated delay in maturity of ReTain™-treated pears at harvests 2 or 3 is illustrated by the transposed harvest day (dotted line) for these treatments from their actual harvest day. The transposed harvest day was interpolated based on the (A) firmness, (B) skin color, or (C) starch content of the ReTain™-treated fruit with respect to control fruit.

applied 14 to 7 d prior to the initial harvest of nontreated fruit to achieve a significant effect on pear maturity, since treatment 21 d before initial harvest had a minimal effect.

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