Commercial Ripening of Cannery Pears with Ethylene

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SUMMARY. 'Bartlett' pears (*Pyrus communis* L.) were harvested and ripened with and without ethylene in standard field bins at a commercial cannery. Mean firmness and firmness uniformity within a bin was evaluated for ethylene- and nonethylene-treated fruit. Uniformity of firmness among pears within a bin increased as ripening progressed. Applying 100 ppm (10 Pa) of ethylene gas during the first 24 hours of commercial ripening accelerated ripening of 'Bartlett' pears held in standard field bins. Improved firmness uniformity would therefore be expected in ethylene-treated fruit commercially ripened to a lower firmness than untreated fruit otherwise ripened and processed at a higher firmness—the improved firmness uniformity was due to the lower firmness and not a specific effect of ethylene on ripening uniformity. When fruit were cold-stored for 20 days at 32 °F (0 °C) before ripening, the mean firmness and firmness uniformity of fruit exposed to ethylene during initial ripening was no different than nonethylene-treated fruit. Results from this study also indicate that fluctuations in ripening room air temperature, under some conditions, might increase firmness variability between fruit within a standard field bin.

In 1996, commercial processing of California 'Bartlett' pears totaled 174,873 tons (158,642 t), of which 88% was canned.

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Pressure on canneries to accommodate such large volumes requires processing freshly harvested, early-season fruit as soon as possible after harvest. Constraints on cold storage space may also force canneries to process freshly harvested fruit. Rapid ripening of 'Bartlett' pears to a uniform firmness is needed to produce a high volume of consistent quality canned product. Ripening a large supply of early season pears to an acceptable, uniform firmness in a short period of time has been problematic for canneries.

Freshly harvested pears, particularly early in the season, ripen slowly and nonuniformly and are of inferior quality if they are not either cold-stored for 2 to 3 weeks at 30 °F (−1 °C) or exposed to ethylene gas before processing (Mitcham, 1994). It is well documented that induction of ripening in pears after cold storage is due to increased biosynthesis of ethylene in the pear tissue (Chen et al., 1983; Gerasopoulos and Richardson, 1997a, 1997b; Sfakiotakis and Dilley, 1974; Wang et al., 1985). Laboratory based studies have demonstrated that exposure to exogenous ethylene can substitute for cold storage in inducing ripening (Blankenship and Richardson, 1985; Hansen and Hartman, 1937; Looney, 1972; Puig et al., 1996). Hansen (1943) noted that small samples of containerized 'Bartlett' pears ripened more rapidly and more uniformly when exposed to either exogenous or endogenous ethylene. Puig et al. (1996) found that firmness uniformity progressively increased as conditioned 'Bartlett' pears (sufficiently chilled, ethylene treated, or combinations of ethylene and chilling) ripened over 5 to 7 d. They demonstrated this by ripening pears in 44-lb (20-kg) boxes under stable room air temperatures of 68 ± 1 °F (20 ± 0.5 °C).

Conditioning 'Bartlett' pears for adequate ripening before processing remains problematic for canneries. The objective of this study was to examine the influence of ethylene gas treatment on the ripening capacity and firmness uniformity of 'Bartlett' pears under standard commercial conditions. We also determined whether existing cannery ripening rooms could maintain ethylene-enriched atmospheres at the required concentrations, and whether the gas could be sufficiently dispersed throughout large, tight stacks of field bins.

Materials and methods

This study was conducted on 'Bartlett' pear fruits obtained from each of two successive growing seasons.

1996 STUDY. Twelve standard field bins of commercially grown, medium-sized, midseason 'Bartlett' pears were obtained from Mendocino County, Calif. from a single harvest. Early season pears were preferred, as this fruit is more responsive to ethylene treatments (Hansen and Hartman, 1937), but were unavailable. The twelve bins of pears were separated into two groups of six bins. One group of six bins was placed into storage at 32 °F (0 °C) (cold-stored fruit) on the property where the fruit was harvested. The other group (noncold-stored fruit) was transported to a large pear canning facility (cannery no. 1). Three bins were placed into each of two commercial ripening rooms under standard commercial ripening room bin stacking configurations, air ventilation, and air temperature management regimes. The volume of each ripening room was $\approx 50,000$ ft³ (1,400 m³) and contained ≈ 600 standard field bins of unripe pears stacked into multiple columns extending many rows out from a false wall acting as a plenum for a serpentine forced-air system. Our experimental fruit were incorporated into a corresponding, centralized column at the rear of each ripening room.

In one storage room, ethylene gas was generated during the initial 24 h of commercial ripening with portable ethylene gas generators (Catalytic Generators Inc., Prattville, Ala.). Ethylene gas production from the generators was based on the room volume and required the dispersion of 10 qt (11.4 L) of 86% ethanol to obtain 100 ppm (10 Pa) over a 24-h period. Air temperature in each room was logged continuously (Monitor Co., Modesto, Calif.) and ethylene concentration at the center of each room was measured every 24 h with precision detector tubes formulated with ethylene-detecting reagents (Matheson Safety Products, East Rutherford, N.J.).

At completion of a 5-d commercial ripening period, each of the three ethylene-treated and nonethylene-treated bins were segregated into 32 evenly distributed 1-ft³ (0.028-m³) volumes, and the firmness of five randomly selected pears from each volume was determined. One of two UC Firmness Testers (Western Industrial Supply Co., San Francisco, Calif.), incorporating

Ametek penetrometers (Ametek Inc., Hatfield, Pa.) fitted with 5/16-inch (8-mm) cylindrical probes, were used for the firmness testing. A firmness tester calibrated for 0 to 30 lb (0 to 133.5 N) force was used to measure firm fruit [≥ 10 lb (44.5 N)] and a second tester calibrated from 0 to 10 lb force was used to measure soft fruit [< 10 lb (44.5 N)]. Two firmness measurements were made on opposite sides of each fruit at the equator, where the skin had been removed. This provided an average firmness from two measurements on each of 160 fruit sourced from 32 evenly distributed positions in each of the three bin replications of both treatments.

The remaining six bins of pears in cold storage [32 °F (0 °C)] were removed after 20 d, transported to the canning facility, and stored in similar locations within two commercial ripening rooms that were each filled to capacity. One of the two rooms was purged with ethylene gas as described above. The pears were ripened for 4 d over which room air temperature and ethylene concentration was monitored as described above. Fruit firmness throughout each of the three replicate bins of ethylene and nonethylene treatments was measured as described previously.

Firmness measurements of cold-stored and noncold-stored fruit were analyzed independently. Each experiment was analyzed as a split-plot design with treatments (ethylene and nonethylene) considered as whole plots, and replications (bins) randomized within. The main effects tested were ethylene treatment, firmness of center and periphery columns of fruit for firmness differences horizontally across the bins, and firmness of upper and lower layers of fruit for firmness differences vertically through the bins. The 32 zones in each bin from which fruit were sampled were grouped to form both a central column of fruit and an encircling column of periphery fruit enabling firmness differences to be tested horizontally across the bins. Regrouping the zones to form an upper and lower fruit layer in each bin enabled firmness differences to be tested vertically through the bins. Standard deviations and coefficients of variation indicated the degree of firmness uniformity within bins of ethylene-treated and nontreated fruit.

1997 STUDY. The effect of ethylene treatment on the ripening capacity and firmness uniformity of 'Bartlett' pears was evaluated at a second com-

mmercial facility (cannery no. 2) under alternative bin stacking arrangements and air circulation capabilities. Six standard field bins of early-season 'Bartlett' pears were harvested from Sacramento County, Calif., on two occasions, 7 d apart, forming two independent evaluations. Pears from the first harvest were unsized (unsized fruit) while pears from the second harvest were graded, small-sized fruit (small-sized fruit). Both groups of six bins were transported to the cannery immediately after harvesting or sizing for commercial ripening. Three bins were loaded into each of two 26,300-ft³ (745-m³) ripening rooms with each room containing four blocks of ≈ 100 tightly stacked field bins of unripened pears (standard cannery procedure). The blocks of bins were separated by a 3-ft (0.91-m) walkway and extended to the walls of the ripening room. Our experimental fruit were positioned within one tightly stacked block of bins at corresponding locations within each room. Ethylene gas was generated (as described above) at the rear of one ripening room for 24 h using 5 qt. (5.7 L) of 86% ethanol to obtain 100 ppm (10 Pa). Air circulation in each ripening room was provided by refrigeration evaporator fans mounted in the ceiling. Air temperature and ethylene concentration near our three bins of experimental fruit in each room was monitored as previously described. The fruit were held under ripening conditions for 4 d, after which firmness of fruit in each bin was measured as previously described.

The six bins of small-sized fruit were also grouped into three bin replications for ripening in each of two commercial ripening rooms. Procedures for the placement of bins in the ripening rooms, ethylene gas treatment, monitoring of air temperature and gas concentration, and fruit firmness measurements were the same as that described for unsized fruit. Cannery personnel extended the duration of the ripening period for this evaluation to 5 d.

Fruit firmness measurements from the unsized and small-sized fruit groups were analyzed independently. Consistent with the analytical procedures from 1996, the bins of ethylene- and nonethylene-treated fruit were tested for firmness differences. Firmness differences between center and periphery or upper and lower layers of fruit within the bins were also tested. Firmness variability throughout bins of ethylene-

treated and nontreated fruit was measured using standard deviations and coefficients of variation.

Results and discussion

1996 Study

NONCOLD-STORED FRUIT. The concentration of ethylene gas in the ethylene-treated room reached 100 ppm (10 Pa) during activation of the ethylene generators (24 h) then declined to 2.5 to 5 ppm (0.25 to 0.5 Pa). Ethylene concentration in the nonethylene-treated room was 0 to 0.5 ppm (0 to 0.05 Pa). Loss of firmness of 'Bartlett' pears during ripening is dependent on temperature (Maxie et al., 1974a). Air temperature in the ethylene-treated and nonethylene-treated ripening rooms remained constant at 70 °F (21 °C) during the initial 4 d of ripening. Cannery personnel gradually lowered the air temperature of both rooms to 50 °F (10 °C) on the final day of ripening. Ethylene-treated pears were 11% or 0.5 lb (2.2 N) softer than nonethylene-treated fruit (Table 1). Fruit firmness was similar between center and periphery fruit and between upper and lower layer fruit. The standard deviation for flesh firmness of each ethylene-treated bin was smaller than nonethylene-treated bins. However, the coefficient of variation, which takes into account differences in the mean firmness, revealed that the variability of fruit firmness between treatments was similar (Table 1). These data indicate that the reduced variability in fruit firmness, given by standard deviation,

was due to the ethylene-treated fruit being softer. Although the rate of fruit ripening was enhanced by exposure to ethylene, the relative firmness uniformity of this fruit was not improved as compared to untreated fruit at the same firmness.

COLD-STORED FRUIT. The ethylene gas levels in the nonethylene- and ethylene-treated ripening rooms for the cold-stored fruit were similar to the noncold-stored fruit. Air temperature in both ripening rooms was constant at 68 °F (20 °C) for the first 3 d of ripening, but was gradually reduced to 45 °F (7 °C) by cannery personnel on the fourth and final day of ripening. Mean fruit firmness of ethylene- and nonethylene-treated pears was similar. Firmness differences between center and periphery columns of fruit were not significant. However, for both treatments, pears in the lower layer of each bin were ≈17% firmer than pears in the upper layer (Fig. 1). Despite this added source of firmness variability, overall distributions of firmness throughout the bins, measured by standard deviations or coefficients of variation, were similar between treatments (Table 1).

1997 Study

UNSIZED FRUIT. Ethylene gas concentration in the ethylene-treated ripening room reached 100 ppm (10 Pa) during activation of the ethylene gas generators (24 h), then declined to 0.5 to 2.5 ppm (0.05 to 0.25 Pa) for the remaining 3 d of ripening. The concentration of ethylene gas in the nonethylene-treated room remained between

0.5 to 2.5 ppm (0.05 to 0.25 Pa) during the 4 d of ripening. Air temperature in the vicinity of our experimental fruit in both ripening rooms fluctuated from ≈41 to 75 °F (5 to 24 °C)—a procedure used by cannery personnel in an attempt to adjust fruit ripening rates to coincide with processing schedules. However, the fluctuating air temperatures between the ethylene and nonethylene treatment rooms were relatively consistent; mean air temperature during ripening was 55 and 56 °F (13 and 13.5 °C), respectively. Unsized, ethylene-treated fruit were 35% or 4.1 lb (18.2 N) softer than nonethylene-treated pears (Table 1). Mean firmness of center and periphery fruit were similar; however, fruit in the lower half of the bins were firmer than fruit in the top, on average by 15% (Fig. 1). Standard deviations of firmness from the ethylene-treated pears were considerably smaller than the nontreated pears (Table 1). However, coefficients of variation revealed that the relative firmness variation between treatments was similar.

SMALL-SIZED FRUIT. The ethylene gas concentration in the ethylene treatment room reached 50 ppm (5 Pa) during activation of the ethylene gas generators (24 h), then declined to 2.5 ppm (0.25 Pa) thereafter; concentration in the nonethylene treatment room containing similar pears was 0.5 to 2.5 ppm (0.05 to 0.25 Pa) during commercial ripening. While the ethylene con-

Table 1. Firmness of 'Bartlett' pears ripened under standard commercial conditions with or without a 24-h ethylene treatment at the start of ripening at cannery no. 1 (1996) or cannery no. 2 (1997).

	1996				1997			
	Fruit							
	Noncold-stored ^z		Cold-stored ^y		Unsize ^y		Small-sized ^x	
	Untreated	Ethylene	Untreated	Ethylene	Untreated	Ethylene	Untreated	Ethylene
Firmness (lb) ^w	3.4	2.9	3.6	3.2	11.5	7.4	9.0	7.5
SD	0.67	0.53	0.64	0.65	2.39	1.40	2.16	1.88
CV	19	19	18	20	21	19	24	25
Significance								
Treatment (T)		***		NS		***		***
Layers (L) ^v		NS		***		***		***
Columns (C) ^u		NS		NS		NS		NS
T × L		NS		NS		NS		NS
T × C		NS		NS		NS		NS

^zRipened 5 d; 100 ppm (10 Pa) used for ethylene treatment.

^yRipened 4 d; 100 ppm (10 Pa) used for ethylene treatment.

^xRipened 5 d; 50 ppm (5 Pa) used for ethylene treatment.

^w1 lb = 4.45 N.

^yDifference in firmness between fruit of the upper and lower layers of the bins.

^uDifference in firmness between fruit of the center and periphery columns of the bins.

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

Fig. 1. Mean fruit firmness of commercially ripened 'Bartlett' pears from the top and bottom half of standard field bins following treatment with or without ethylene during initial ripening. Vertical bars are standard errors. Different letters within the treatments of the noncold-stored, cold-stored, unsized, or small-sized fruit groups illustrate significant differences between mean firmness of fruit from the top and bottom half of the bins ($P < 0.05$). 1 lb = 4.45 N.

centration was lower than the intended 100 ppm (10 Pa) in the ethylene treatment room, only 10 ppm (1 Pa) is needed to stimulate fruit ripening (Mitcham, 1994). Air temperature near our experimental fruit fluctuated from ≈ 42 to 70°F (6 to 21°C) in both ripening rooms with relative consistency. However, our nonethylene-treated control fruit were held for 18 h at a mean temperature of 86°F (30°C) before ripening due to the delayed filling of the control room with commercial fruit. Mean ripening room air temperature for the ethylene-treated fruit over the same 18 h was 66°F (19°C). In addition, cannery personnel processed the commercial pears in both ripening rooms ahead of schedule forcing our experimental fruit to be stored for 18 h at a mean temperature of 82°F (28°C) before firmness evaluation. Mean air temperature surrounding the ethylene- and nonethylene-treated fruit from de-

livery of the pears at the cannery to firmness evaluation following ripening was 61°F (16°C) and 66°F (19°C), respectively.

Small-sized, ethylene-treated pears were 17% or 1.5 lb (6.7 N) less firm than nonethylene-treated pears (Table 1). Consistent with the previous evaluation, firmness differences within bins were not significant between center and periphery fruit, but were significant between upper layer and lower layer fruit. Pears in the lower half of the bins were 19% and 17% firmer for the ethylene and nonethylene treatments, respectively (Fig. 1). Overall firmness variability throughout the bins, measured by standard deviation, was lower in ethylene-treated fruit. Relative firmness variability, given by coefficient of variation, was similar between ethylene- and nonethylene-treated fruit (Table 1).

Despite the additional day of ripening and average warmer temperatures received by the small-sized fruit, the ethylene-treated pears did not soften more than the ethylene-treated unsized fruit. In contrast, the nonethylene-treated small-sized fruit softened considerably more than the unsized nonethylene-treated fruit (Table 1). This result may indicate that the ethylene gas concentration of 50 ppm (5 Pa) in the ripening room was insufficient to fully promote ripening throughout the bins of the small-sized fruit. It is also possible that the elevated temperatures experienced by the small-sized fruit may have suppressed ripening. Maxie et al. (1974b) stated that at any stage of ripeness of 'Bartlett' pears, subsequent ripening was inhibited or reduced when the fruit were warmed to 86 or 104°F (30 or 40°C), respectively. However, the lack of evidence for ripening suppression in the small-sized, untreated fruit, exposed to temperatures at or close to 86°F (30°C) for 18 h on the first and last day of ripening, suggests that low ethylene concentration is responsible for the slower ripening of ethylene-treated small-sized pears as compared with ethylene-treated unsized pears.

Temperature management during ripening

Temperature management within the ripening room may be an important factor affecting firmness uniformity of the ripened fruit. Monitoring numerous fruit temperatures within field bins of pears experiencing static-air cooling

showed that cooling fronts originating beneath the floor vents of the bins slowly traverse vertically through the pears (Mitcham et al., 1996). They stated that this resulted in fruit at the bottom of the bins attaining seven-eighths cooling 18 h ahead of fruit at the top of the bins, and that this nonuniform cooling can disrupt the uniformity of ripening between fruit from the different layers of the bin. Mitcham et al. (1997) found that firmness uniformity of 'Bartlett' pears ripened in field bins was improved when the pears were forced-air rather than static-air cooled before cold storage.

In this study, fruit in the bottom of the bin were 15% to 19% firmer than fruit in the top of the bin except for the noncold-stored fruit of the 1996 study (Fig. 1). It is probable that firmness uniformity between the top and bottom fruit layers of the cold-stored pears was disrupted due to static-air cooling of this fruit during cold storage before ripening. Firmness differentials between top and bottom fruit layers of the unsized and small-sized pears may also have been caused by static-air cooling through excessive air temperature fluctuations during ripening of this fruit at cannery no. 2 (magnitude of fluctuations described previously). The lack of differences in firmness between fruit layers for the noncold-stored pears in the 1996 study may be attributed to a relatively stable ripening room air temperature at cannery no. 1 (magnitude of fluctuations described previously) during fruit ripening and to forced- as opposed to static-air cooling or warming of fruit at this cannery during ripening. These results suggest that fluctuating air temperatures during ripening of 'Bartlett' pears held in field bins should be avoided to prevent additional reductions in fruit ripening uniformity, especially when forced-air systems are unavailable. Maxie et al. (1974a) similarly commented that variability of ripeness between 'Bartlett' pears at the time of canning may be related to excessive fluctuations in ripening room air temperatures.

Conclusions

The results of this study indicate that a 24-h exposure to 100 ppm (10 Pa) of ethylene during ripening will accelerate ripening of noncold-stored early- or midseason 'Bartlett' pears. A 24-h exposure to 50-ppm (5-Pa) ethylene in a poorly ventilated commercial ripening room may be insufficient for

obtaining the full benefit of the gas treatment. The two very distinctive commercial ripening rooms used in this study—one accommodating relatively loosely stacked bins ventilated by forced air and the other accommodating blocks of tightly stacked bins ventilated by ceiling-mounted fans—sufficiently contained and dispersed ethylene gas at concentrations of 100 ppm (10 Pa).

Overall firmness variability, measured by standard deviation, was reduced in bins of ethylene-treated pears that were not subjected to cold storage before ripening. However, coefficients of variation for each bin were relatively consistent between ethylene- and nonethylene-treated pears, even between contrastingly soft (1996 study) and firm (1997 study) fruit, suggesting that variability of firmness between pears in field bins was not specifically reduced by ethylene treatment, but naturally decreases as the pears soften. Our results suggest that barring any influence of air temperature gradients during ripening, firmness uniformity can be improved in bins of pears only by ripening to a lower firmness. Ethylene treatment during ripening allows for faster ripening, a benefit to canneries with limited ripening facilities.

For commercial ripening of 'Bartlett' pears held in field bins, an ethylene gas treatment should be applied during the initial 24 h of ripening while fruit are held at $\approx 68^{\circ}\text{F}$ (20°C). The portable ethylene gas generators used in this study were commercially available units featuring a relatively low operational cost. The number of gas generators and operational settings required to obtain 100 ppm (10 Pa) in a commercial ripening room will depend on the volume and gas tightness of the room, the density of bin stacking, and ventilation capacity of the room. Ethylene gas concentration should be monitored at regular intervals to ensure the desired concentration is obtained. Ripening rooms should be held at a constant temperature (55 to 70°F ; 13 to 21°C) during fruit ripening to maintain uniform fruit temperatures and therefore uniform rates of ripening.

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