PRECONDITION OF 'D'ANJOU' PEARS FOR EARLY MARKETING BY ETHYLENE TREATMENT

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ABSTRACT

*'D'Anjou' pears (*Pyrus communis, L.*) harvested at an optimum maturity with the flesh firmness (FF) of 66.7N required 8 weeks of chilling at -1C in order to initiate normal ripening in an ethylene-free environment at room temperature. If harvested fruit were not exposed to chilling or chilled at -1C for less than 8 weeks, they could be preconditioned with 100 ppm ethylene for 3 days at 20C to initiate normal ripening. Fruit preconditioned with ethylene were capable of softening normally, reducing extractable juice, decreasing titratable acidity, and showing the climacteric rise of ethylene production during ripening at 20C when treated fruit had been further held at -1C in air for 14 days. The properly ripened fruit developed an acceptable dessert quality. When 'd 'Anjou' fruits had been stored at -1C in air for 8 weeks or longer, they could also be preconditioned without ethylene for 3 days at 20C to enhance ripening capacity. The nonethylene preconditioned fruit were capable of ripening normally following 14 days in simulated transit at -1C and upon arrival in retail markets at room temperature.*

INTRODUCTION

The increase in production of 'd'Anjou' pears (*Pyrus communis, L.*) in the Pacific Northwest has forced the pear industry to evaluate the feasibility of marketing the fruit shortly after harvest. The Pacific Northwest produced 11.2 million boxes (20 kg/box) of 'd'Anjou' pears in 1994 and will continue to increase the production within the next five years. It is not recommended to market 'd'Anjou' pears shortly after commercial harvest because they, similar to most

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winter pear cultivars, require a period of chilling to induce normal ripening capacity (Blankenship and Richardson 1985; Drouet and Hartmann 1979; Knee 1987; Leblond and Ularich 1973; Morin *et al.* 1985). Our previous study showed that 'd'Anjou' fruit harvested at commercial maturity with flesh firmness between 66.7N (15 lbs force) and 57.8N (13 lbs force) required a period of 60 days at -1C to generate normal ripening capacity (Chen and Mellenthin 1981). A recent study by Kupferman and his coworkers has shown that commercially packed 'd'Anjou'pears shipped before November did not soften properly after 7 days of ripening at room temperature (Kupferman 1994). Therefore, the consumer could not obtain 'd'Anjou' fruit with a desirable eating quality from September to October each year.

It has long been recognized from a consumer perspective that the ripening of winter pears, particularly 'd'Anjou', has been a deterrent in consumer purchases of the fruit. Various education and promotion activities through the years have not resulted in the desired customer perception to understand the basic ripening procedure of winter pears. In an effort to make ripened, or partially ripened fruit an easy and desirable purchase for shoppers, we re-investigated the feasibility of making "preconditioned" 'd'Anjou' fruit available to retailers. The method for preconditioning 'd'Anjou' pears involves the warming of stored fruit at 20C for a few days with or without ethylene in a preconditioning room, just prior to the shipment. The preconditioned fruit are then cooled to a temperature of -1C for further handling and shipping. It would be preferable to the pear industry to have 'd'Anjou' fruit "preconditioned" at the production site rather than at the retail markets where the facilities may be limited and the labor costs are usually higher. To be commercially feasible, "preconditioned" fruit must remain green and firm with no risk of bruising during shipping and distribution, ripen swiftly in air at the retail markets, and develop juicy and flavorful qualities upon reaching the consumers.

The objective of this study was to induce the normal ripening potential of 'd'Anjou' pears, which have had minimal exposure to chilling temperature, by preconditioning them with or without ethylene for 3 days at 20C.

MATERIALS AND METHODS

'D'Anjou' pears were harvested at commercial maturity with flesh firmness (FF) of 66.7N (±2.5N) from an orchard block with 67 mature trees located at Mid-Columbia Agricultural Research and Extension Center, Hood River, Oregon. Harvested fruit were randomly transferred into 30 wooden boxes (20 kg/box) with polyethylene liners and held in cold storage at -1C in air.

At harvest and after 2, 4, 6, and 8 weeks of storage, three boxes of fruit were randomly removed from the cold storage and conditioned in a room enriched with 100 ppm ethylene (±20 ppm), and another three boxes of fruit were conditioned in a room without ethylene (<0.01 ppm) for 3 days at 20C. The relative humidity in both rooms was maintained at 70% or slightly lower. The concentration of ethylene in the preconditioning room was set at 100 ppm according to literature published for the induction of ripening activities of other fruit crops (Brecht and Kader 1984a; Brecht and Kader 1984b; Hesselman and Freebairn 1969). After the end of the 3-day preconditioning treatments, changes in flesh firmness (FF), extractable juice (EJ), titratable acidity (TA) and soluble solids concentration (SSC) in the treated fruit (10 fruits per box) were determined as described previously (Chen and Borgic 1985; Chen and Mellenthin 1981). Treated fruit were then returned to the cold storage in air at-1C and held for 14 days to simulate the period of further handling and shipping to the retail markets.

After 14 days of holding, preconditioned fruit were ripened at 20C in an ethylenefree room (<0.01 ppm C_2H_4) with a relative humidity of 85%. After day 1, 3, 5, and 8 of ripening, changes in FF (softening pattern), EJ, TA and SSC were determined. At the beginning of each ripening interval, a five-fruit sample from each box was also transferred into a respiration chamber with a constant flow of ethylene-free air at 200 mL/min at 20C for the measurement of ethylene production from ripening fruit. The rates of ethylene production were determined daily for 15 days by gas chromatography (Chen and Mellenthin 1981).

After day 7 of ripening, the dessert qualities including texture and flavor (acid/sugar balance and aroma) were assessed by three trained panelists and rated on a nine-point hedonic scale with 9 = buttery and juicy texture and flavorful taste and 1 = mealy, coarse, and dry texture and off flavor (McBride 1986). Each panelist was given the same fruit samples randomly selected from each box. Three fruit from each box were randomly selected and assessed at each ripening interval. The procedures for sensory evaluation of horticultural crops (Heintz and Kader 1983) were adopted by the panelists. All fruit were chilled at -1C overnight and then warmed at 20C for 2h prior to quality assessment. An average score of 5 or higher was arbitrarily defined as "commercially acceptable".

Data obtained from a 3-day preconditioning treatment after each storage interval were subjected to a split-plot 2-way analysis of variance (ANOVA) where the 3-day preconditioning treatment (100 ppm ethylene or nonethylene) was considered as the main plot and the storage intervals (weeks) as the sub-plot. For both ethylene and nonethylene treatments, each box was considered as a replicate and a 10-fruit sample from each box as an experimental unit. Therefore, each treatment (ethylene or nonethylene) was replicated three times for a 3-day preconditioning treatment. Means of each measurement (i.e., FF, EJ, TA, and SSC) were separated by the least significant difference at the 5% level ($LSD_{.05}$).

Data obtained from the 8-day ripening treatment were first subjected to a split-plot 3-way ANOVA where the 3-day preconditioning treatment (ethylene or nonethylene) was also considered as the whole plot and the storage intervals (weeks) and days of ripening were the randomized sub-plots. For both preconditioning treatments, each box was also considered as a replicate and either a 10-fruit sample (for the measurement of FF, EJ, TA, and SSC) or a 5-fruit sample (for the measurement of ethylene production) was considered as an experimental unit. Therefore, each treatment was also replicated three times at each measuring interval during ripening. If the preconditioning treatments, the storage intervals and days of ripening were found to be significantly different and to have a significant interaction, changes in such measurement (dependent variable) were plotted against days of ripening (independent variable) for each storage interval. In order to elucidate the general trend of changing pattern of each measurement, the curve fitting was conducted as the following function types: (1) linear; (2) exponential; (3) natural logarithmic; (4) power law; and (5) polynomial. The type of function with the highest significant R^2 correlation coefficient was selected as the best fit for each curve. NWA STATPAK 4.1 (Northwest Analytical, Inc., Portland, OR,USA) was used for these statistical analyses. Means of each measurement were also separated by $LSD_{.05}$.

For the assessments of dessert quality, each box was also considered as a replicate and a 3-fruit sample as an experimental unit. Again, each treatment was replicated three times at each assessing interval. The average quality score assessed by three panelists for a 3-fruit experimental unit from each replicate (box) was used for the calculation of standard errors to compare means between preconditioning treatments and among ripening intervals.

RESULTS

Preconditioning Treatment

Fruit were harvested on August 31, 1994 with an average FF of 66.7N. A 3-day preconditioning treatment with 100 ppm ethylene decreased FF of the fruit to 64.4N at harvest and to between 61.7N and 60.6N after fruit had been stored at -1C for 2 to 6 weeks (Table 1). After 8 weeks of cold storage, a 3-day ethylene preconditioning treatment decreased FF of the fruit further to 50.7N. A 3-day nonethylene preconditioning treatment did not reduce FF of the fruit regardless of the storage intervals (Table 1). The highly significant interaction between the preconditioning treatments and the storage intervals indicated that the changes in FF of the preconditioned fruit were not parallel between ethylene and nonethylene treatments during 8 weeks of storage intervals.

Changes in extractable juice (EJ) in fruit after a 3-day preconditioning were not significantly different among the storage intervals (Table 1). Fruit preconditioned with 100 ppm ethylene had less EJ as compared with those preconditioned without ethylene (Table 1).

There were no significant differences in titratable acidity (TA) and soluble solids concentration (SSC) between 100 ppm ethylene and no ethylene preconditioning treatments (Table 1). Fruit stored for 8 weeks reduced TA significantly as compared to those stored for 6 weeks or shorter. Fruit stored for

TABLE 1.
DIFFERENCES IN FLESH FIRMNESS (FF), EXTRACTABLE JUICE (EJ), TITRATABLE ACIDITY (TA), AND SOLUABLE SOLIDS CONCENTRATION (SSC) IN 'D'ANJOU' PEARS TREATED WITH 100 PPM ETHYLENE (C_2H_4) OR WITHOUT ETHYLENE (NO C_2H_4) FOR 3 DAYS AT 20C AFTER DIFFERENT STORAGE INTERVALS IN AIR AT-1C.

Treatment	Storage Interval (Weeks)	FF (N)	EJ ($ml \bullet 100\ g^{-1}$)	TA ($meg \bullet 100\ ml^{-1}$)	SSC (%)
C_2H_4	At Harvest	64.4	63.3	5.9	13.4
	2	61.7	65.0	5.8	13.7
	4	61.1	63.7	5.7	14.3
	6	60.6	59.3	5.6	14.0
	8	50.7	62.1	4.9	14.7
No C_2H_4	At Harvest	66.7	66.0	5.3	13.1
	2	67.6	67.1	5.7	13.9
	4	70.8	65.8	5.3	14.2
	6	65.1	65.0	5.5	14.7
	8	67.1	65.7	4.9	14.7
$LSD_{.05}$	$LSD_{.05}$	3.7	2.8	0.5	0.8
Sources	D.F.	Significance			
Pre-cond.(P)	1	**	*	ns	ns
Storage (S)	4	**	ns	**	*
P x S	4	**	ns	ns	ns

ns, *, ** Not significant, significant at $P \leq 0.05$, or at $P \leq 0.01$, respectively.

2 weeks or longer had significantly higher SSC compared with fruit at harvest.

Ripening Activities after Simulated Transit

After 14 days in simulated transit at -1C, changes in FF were highly significant between preconditioning treatments (ethylene vs nonethylene), storage intervals (weeks), and ripening period (days). There were also strong interactions between the sources of variance. The quadratic function was found to be the best fit for the softening curve at each ripening interval. At the end of the 14-day simulated transit period, the ethylene preconditioned fruit softened from between 64.4N and 50.7N (Table 1) to between 53.4N (12 lbs-force) and 35.6N (8 lbs-force) depending upon the different storage intervals as shown on day 1 of ripening (Fig. lA). The nonethylene preconditioned fruit did not soften or softened to no less than 62.3N (14 lbs-force) (Fig. 1B). During 8 days of ripening at 20C, those fruit preconditioned with 100 ppm ethylene after 2 to 8 weeks of storage softened normally to the proper ripeness (≤18N) on day 5 and continued to soften to 9N on day 8 (Fig. 1A). The fruit preconditioned with 100 ppm ethylene immediately after harvest softened to 26.7N on day 8 of ripening, indicating they were only partially ripe (Fig. lA). The proper softness of winter pears upon ripening is between 11N and 18N. The normal ripening potential of 'd'Anjou' fruit could not be initiated by preconditioning them under the nonethylene treatment if the fruit were treated immediately after harvest or stored for less than 8 weeks at -1C. Only fruit stored for 8 weeks could be preconditioned under nonethylene environment for the initiation of normal ripening potential. The fruit preconditioned without ethylene at harvest did not soften during 8 days of ripening at 20C indicated by the insignificant R^2 value (0.6482) of the quadratic equation (Fig. 1B). Those fruit preconditioned without ethylene after 2 and 4 weeks of storage softened to 35.6N and 26.7N respectively, after 8 days of ripening indicating that they did not ripen properly or only softened without developing other normal ripening characteristics (Fig. 1B). Wang *et al.* (1972) reported that softening of pears occurred prior to, and was not dependent on, development of the climacteric rise.

After 14 days in simulated transit, changes in EJ content were also highly significant between preconditioning treatments, storage intervals, and days of ripening. The sources of variance were significantly interactive. The quadratic function was also the best fit for each EJ curve. At the end of 14-day simulated transit, EJ of the ethylene preconditioned fruit was between 57 and 60 mL/100g fresh weight on day 1 of ripening if the fruit were preconditioned after 2 to 8 weeks of storage (Fig. 2A). The results indicated that these fruit were partially ripened in transit since the EJ content in the untreated unripened 'd'Anjou"pears was around 68 mL/100 g fresh weight. The fruit preconditioned with 100 ppm ethylene reduced the EJ content to 53 mL or lower after 5 days of ripening and

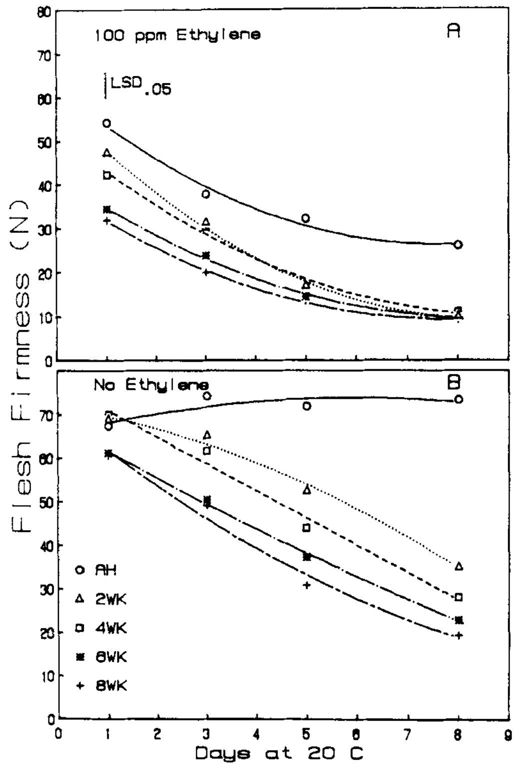

FIG. 1. CHANGES IN FLESH FIRMNESS (FF) OF ETHYLENE PRECONDITIONED (A) AND NONETHYLENE PRECONDITIONED (B) 'D'ANJOU' PEARS DURING 8 DAYS OF RIPENING AT 20C

Fruit were harvested on August 31, 1994 with an average FF of 66.7N, stored in wooden boxes (20 kg/box) with polyethylene liners at -1C in air for 0 (AH), 2, 4, 6, and 8 weeks, and then preconditioned with 100 ppm ethylene or no ethylene (< 0.01 ppm) at 20C for 3 days. The preconditioned fruit had been kept at -1C in simulated transit for 14 days at each storage interval prior to the ripening experiment.

The quadratic equations for each storage interval are:

A) 100 ppm ethylene

FF(AH) = 62.22 - 9.40D + 0.62D^2(R^2 0.9852**);
FF(2 wks) = 58.56 -11.49D + 0.67D^2 (R^2 0.9968**);
FF(4 wks) = 51.58 - 9.12D + 0.50D^2 (R^2 0.9921**);
FF(6 wks) = 41.93 - 7.63D + 0.45D^2 (R^2 0.9978**);
FF(8 wks) = 38.75 - 7.54D + 0.48D^2 (R^2 0.9983**);

B) No ethylene

FF(AH) = 65.59 + 2.79D - 0.24D^2 (R^2 0.6482^{ns});
FF(2 wks) = 71.62 - 1.71D - 0.36D^2 (R^2 0.9904**);
FF(4 wks) = 77.04 - 6.07D - 0.01D^2 (R^2 0.9849**);
FF(6 wks) = 67.84 - 6.39D + 0.09D^2 (R^2 0.9978**);
FF(8 wks) = 70.58 - 9.15D + 0.34D^2 (R^2 0.9842**);
(Where D represents days of ripening at 20C).

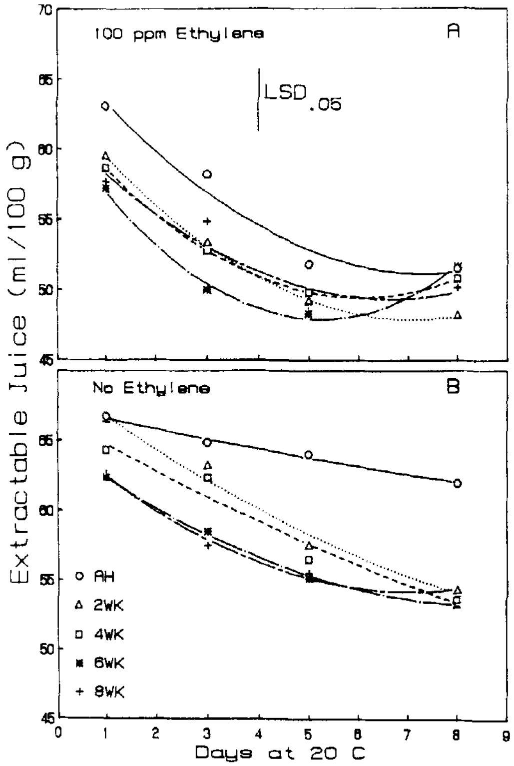

FIG. 2. CHANGES IN EXTRACTABLE JUICE (EJ) OF ETHYLENE PRECONDITIONED (A) AND NONETHYLENE PRECONDITIONED (B) 'D'ANJOU' PEARS DURING 8 DAYS OF RIPENING AT 20C

Fruit were harvested on August 31, 1994 with an average FF of 66.7N, stored in wooden boxes (20 kg/box) with polyethylene liners at -1C in air for 0 (AH), 2, 4, 6, and 8 weeks, and then preconditioned with 100 ppm ethylene or no ethylene (< 0.01 ppm) at 20C for 3 days. The *preconditioned fruit had been kept at -1C in simulated transit for 14 days at each storage interval* prior to the ripening experiment.

The quadratic equations for each storage interval are:

A) 100 ppm ethylene

EJ(AH) = 67.60 - 9.46D + 0.30D^2 (R^2 0.969*);
EJ(2 wks) = 63.54 - 4.43D + 0.31D^2 (R^2 0.9984**);
EJ(4 wks) = 62.89 - 4.58D + 0.40D^2 (R^2 0.9995**);
EJ(6 wks) = 58.66 - 4.07D + 0.40D^2 (R^2 0.9999**);
EJ(8 wks) = 61.72 - 3.71D + 0.28D^2 (R^2 0.9187*);

B) No ethylene

EJ (AH) = 67.36 - 0.81D + 0.02D^2 (R^2 0.9878**);
EJ (2 wks) = 69.51 - 2.76D + 0.10D^2 (R^2 0.9795*);
EJ (4 wks) = 67.96 - 3.80D + 0.20D^2 (R^2 0.9998**);
EJ (6 wks) = 64.80 - 2.31D + 0.05D^2 (R^2 0.9868**);
EJ (8 wks) = 66.86 - 4.46D + 0.32D^2 (R^2 0.9996**);
(When D represents days of ripening at 20C).

remained at that level after 8 days of ripening if the fruit were preconditioned between 2 and 8 weeks of cold storage (Fig. 2A). The results indicated that these fruit were capable of ripening with juicy and buttery texture on day 5 and maintaining this texture quality even after 8 days of ripening. The fruit preconditioned without ethylene immediately after harvest did not show any reduction in EJ content during 8 days of ripening (Fig. 2B). Although fruit preconditioned without ethylene after 2 to 8 weeks of cold storage reduced their EJ content during 8 days of ripening, the EJ content never dropped below 55 mL even on day 8 of ripening (Fig. 2B) indicating these nonethylene treated fruit ripened with less buttery and juicy texture than those fruit preconditioned with ethylene.

Changes in TA were highly significant between preconditioning treatments, storage intervals, and days of ripening with significant interactions between preconditioning treatments and storage intervals, and between preconditioning treatments and days of ripening. Storage intervals and days of ripening were not significantly interactive. The linear function was found to be the best fit for TA data (Fig. 3A and 3B). TA in ethylene preconditioned fruit were lower than those in nonethylene preconditioned fruit. There was a consistent drop in TA during storage period regardless of different preconditioning treatments. At each ripening interval, TA in ethylene preconditioned fruit decreased linearly during 8 days of ripening (Fig. 3A) indicating that organic acids in pear fruit were a part of carbon and energy sources required for respiration during storage and for the metabolic activities during ripening (Chen *et al.* 1983). However, TA in nonethylene preconditioned fruit did not change significantly during 8 days of ripening as indicated by the insignificant R^2 values of each linear equation regardless of different storage intervals (Fig. 3B). TA in nonethylene treated fruit also showed a decreasing pattern during 8 days of ripening if they were treated after 6 or 8 weeks of storage even though the decreasing patterns were not statistically significant (Fig. 3B).

Changes in SSC were not significantly different between ethylene and nonethylene preconditioning treatments and among days of ripening; but were highly significant among storage intervals (Data not presented). SSC in fruit immediately at harvest and after 2 weeks of storage were between 13.5% and 14% and increased to between 14.5% and 15% after 6 or 8 weeks of storage. At each ripening interval, SSC in fruit did not change during the 8-day ripening period (Data not presented). The results indicated that increase in SSC was mainly due to the conversion of starch to soluble sugars during storage period (Chen and Mellenthin 1981).

For the preconditioning treatment with 100 ppm ethylene, fruit treated immediately after harvest generated small but increasing amounts of ethylene during 15 days of ripening and the ethylene production did not pass the climacteric peak (Fig. 4A). Fruit preconditioned with ethylene after 2 to 6 weeks of cold storage showed the typical schemes of ethylene climacteric rise. Each curve fits

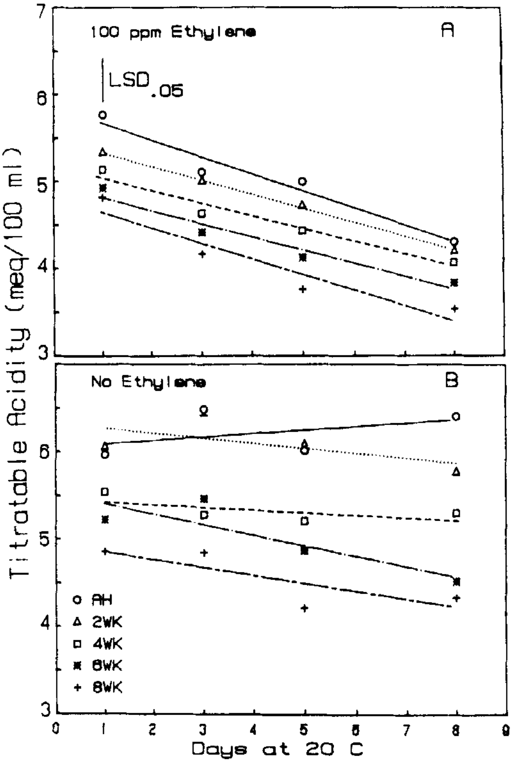

FIG. 3. CHANGES IN TITRATABLE ACIDITY (TA) OF ETHYLENE PRECONDITIONED (A) AND NONETHYLENE PRECONDITIONED (B) 'D'ANJOU' PEARS DURING 8 DAYS OF RIPENING AT 20C

Fruit were harvested on August 31, 1994 with an average FF of 66.7N, stored in wooden boxes (20 kg/box) with polyethylene liners at -1C in air for 0 (AH), 2, 4, 6, and 8 weeks, and then preconditioned with 100 ppm ethylene or no ethylene (< 0.01 ppm) at 20C for 3 days. The preconditioned fruit had been kept at -1C in simulated transit for 14 days at each storage interval prior to the ripening experiment.

The linear equations for each storage interval are:

A) 100 ppm ethylene

TA(AH) = 5.87 - 0.20D (R^2 0.9529*);
TA(2 wks) = 5.49 - 0.16D (R^2 0.9991**);
TA(4 wks) = 5.18 - 0.14D (R^2 0.9568*);
TA(6 wks) = 4.97 - 0.15D (R^2 0.9514*);
TA(8 wks) = 4.83 - 0.18D (R^2 0.9064*);

B) No ethylene

TA(AH)=6.05 + 0.04D (R^2 0.1976^{ns});
TA(2 wks)=6.33-0.06D(R^2 0.3823^{ns});
TA(4 wks)=5.46-0.03D(R^2 0.3838^{ns});
TA(6 wks)=5.54-0.12D(R^2 0.7525^{ns});
TA(8 wks)=4.95-0.09D(R^2 0.6466^{ns});
(Where D represents days of ripening at 20C).

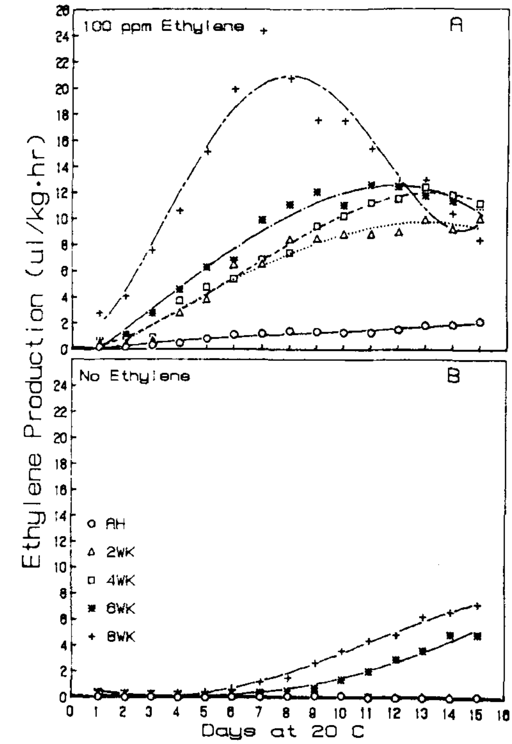

FIG.4. CHANGES IN ETHYLENE PRODUCTION (EP) OF ETHYLENE PRE-CONDITIONED (A) AND NON-ETHYLENE PRECONDITIONED (B) 'D'ANJOU' PEARS DURING 8 DAYS OF RIPENING AT 20C

Fruit were harvested on August 31, 1994 with an average FF of 66.7N, stored in wooden boxes (20 kg/box) with polyethylene liners at -1C in air for 0 (AH), 2, 4, 6, and 8 weeks, and then preconditioned with 100 ppm ethylene or no ethylene (<0.01 ppm) at 20C for 3 days. The preconditioned fruit had been kept at-1C in simulated transit for 14 days at each storage interval prior to the ripening experiment.

The third or fourth order of polynomial equations for each storage interval are:

A) 100 ppm ethylene

$EP(AH) = -0.33+0.34D - 0.03D^2 + 0.01D^3$ (R^2 0.9526*);
$EP(2\ wks) = -1.78+1.18D + 0.02D^2 - 0.01D^3$ (R^2 0.9634*);
$EP(4\ wks) = -0.17 + 0.25D + 0.17D^2 - 0.01D^3$ (R^2 0.9899**);
$EP(6\ wks) = -1.36 + 1.35D + 0.07D^2 - 0.01D^3$ (R^2 0.9799*);
$EP(8\ wks) = 1.59-0.93D+ 1.55D^2 -0.19D^3+ 0.01D^4$ (R^2 0.9274*);

B) No ethylene

$EP(AH) = 0.02 - 0.00D + 0.00D^2 - 0.00D^3$ (R^2 0.1197^{ns});
$EP(2\ wks) = 0.24 - 0.05 + 0.00D^2 - 0.00D^3$ (R^2 0.3223^{ns});
$EP(4\ wks) = 0.38 - 0.15D + 0.02D^2 - 0.00D^3$ (R^2 0.5957^{ns});
$EP(6\ wks) = 0.77 - 0.30D + 0.03D^2 + 0.00D^3$ (R^2 0.9804**);
$EP(8\ wks) = 1.21 - 0.76D + 0.14D^2 - 0.00D^3$ (R^2 0.9928**);
(Where D represents days of ripening at 20C).

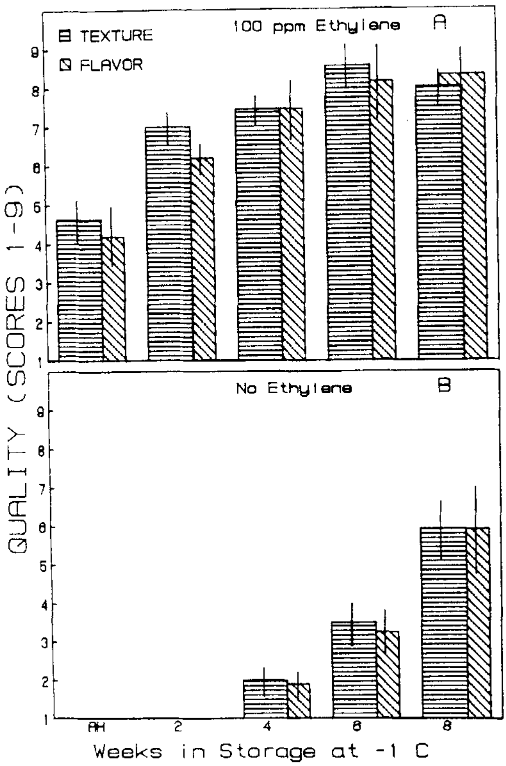

FIG. 5. SCORES OF THE DESSERT QUALITIES OF THE RIPENED 'D'ANJOU' PEARS PRECONDITIONED WITH EITHER 100 PPM ETHYLENE (A) OR NO ETHYLENE (B) FOR 3 DAYS AT 20C AFTER 0 (AH), 2, 4, 6, AND 8 WEEKS OF STORAGE IN AIR AT -1C

The preconditioned fruit had been kept at -1C in simulated transit for 14 days at each storage interval prior to the ripening experiment. The vertical line on each bar graph represents the standard error.

a third order polynomial function well. The ethylene production of ripening 'd'Anjou' fruit reached the climacteric peaks on day 13 or 14 of ripening (Fig. 4A). Fruit preconditioned with ethylene after 8 weeks of cold storage showed very high rates of ethylene production during ripening. The fourth order polynomial function was found to be the best fit for the data (Fig. 4A). The ethylene production reached the peak on day 8 of ripening indicating that this group of fruit had already satisfied the normal chilling requirement and a 3-day ethylene preconditioning treatment enhanced their ripening activities (Fig. 4A).

Fruit preconditioned without ethylene immediately after harvest and after 2 to 4 weeks of storage generated only trace amounts of ethylene production during 15 days of ripening indicating these fruit were incapable of ripening normally (Fig. 4B). Fruit preconditioned without ethylene after 6 and 8 weeks of storage were capable of producing low levels of ethylene during 15 days of ripening; however, the rates of ethylene production never reached the climacteric peak (Fig. 4B). Even though nonethylene treated fruit produced very low rates of ethylene production during ripening, they were also capable of softening and reducing EJ to a certain extent (Fig. lB and 2B). It was evident that the minimal amount of ethylene generated from nonethylene treated fruit was sufficient enough to trigger other ripening reactions similar to the findings reported by Wang and Hansen (1970) and by Wang *et al.* (1972).

The ethylene preconditioned 'd'Anjou' fruit developed acceptable dessert qualities (including texture and flavor) upon ripening on day 7 even though they were preconditioned immediately after harvest (Fig. 5A). The dessert qualities of the ripened fruit preconditioned with ethylene after 2 to 8 weeks of storage improved to no less than a score of 7 on a 9-point hedonic scale (Fig. 5A). The non-ethylene preconditioned fruit, on the other hand, did not ripen with acceptable dessert qualities until the fruit had been stored for 8 weeks at -1C (Fig. 5B). The results indicated that 'd'Anjou' pears harvested at the optimum maturity with the flesh firmness of 66.7N required a minimum of 8 weeks of chilling at -1C in order to induce normal ripening.

DISCUSSION

This study demonstrated that 'd'Anjou' pears harvested at the optimum maturity required external ethylene in order to initiate ripening immediately after harvest or after cold storage for less than 8 weeks. Harvested fruit could be preconditioned with 100 ppm ethylene immediately after harvest or after being stored at -1C for less than 8 weeks. Preconditioned fruit could then be safely packed and shipped to retail markets with minimal risk of blemishing since FF of the treated fruit was no less than 50.7N (Mellenthin and Chen 1981) after 3 days of preconditioning under 100 ppm ethylene at 20C (Table l). Fruit preconditioned with 100 ppm ethylene were also capable of ripening swiftly at retail markets (Fig.1A, 2A and 4A). If fruit had been stored for 8 weeks or longer, they had satisfied the chilling requirement, and therefore could be preconditioned without ethylene to enhance ripening (Fig. lB, 2B and 4B). Preconditioning treatment (with or without ethylene) was also found to be effective to induce ripening capacity of commercially packed 'd'Anjou' fruit (Puig *et al.* 1995).

Ethylene has been commercially applied to initiate the ripening of banana fruit. Although the threshold concentration of ethylene required for the initiation of ripening of banana fruit is very low, i.e., between 0.1 and 1.0 ppm (Reid 1992), the actual ethylene concentrations commercially used to treat banana fruit are between 100 and 1,000 ppm (Sommer and Arpaia 1992). The time required for treatment is between 4 and 24 h (Hesselman and Freebairn 1969; Liu 1976a; Liu 1976b; Sommer and Arpaia 1992). Commercial application of ethylene to initiate ripening of winter pears has not been reported. Ethylene was used to study the basic mechanisms of ripening in several cultivars of pear fruit at different stages of maturity (Blanpied and Hansen 1986; Hansen 1937; Hansen 1943; Hansen 1967; Hansen and Blanpied 1968; Wang and Hansen 1970; Wang *et al.* 1972). Wang *et al* (1972) reported that the ethylene concentration affecting ripening decreased progressively during fruit maturation and the threshold levels of ethylene required to induce ripening were between 0.05 and 2 ppm depending upon the stage of maturation. In this study, we applied 100 ppm ethylene to precondition 'd'Anjou' pears harvested at the optimum maturity to insure that the ethylene dosage was above the reported threshold level.

Hansen and Blanpied (1968) found that the optimum length of ethylene treatment required to induce ripening in 'Bosc' pears varied according to maturity. Premature 'Bosc' fruit required 48 h as compared to 24 h for fully mature fruit. Ripening in post-mature 'Bosc' fruit proceeded without exposure to ethylene but was stimulated by a 12-h ethylene treatment. Rate of ripening also increased with advance in fruit maturity. In the Pacific Northwest, the commercial harvest period of 'd'Anjou' pears in each season can be stretched for as long as 3 weeks in any pear producing districts due to heavy crop load and/or labor shortages (Information obtained from several packing houses in the Pacific Northwest by personal communication). Therefore, the stages of maturity of commercially harvested 'd'Anjou' pears could be varied from season to season at different pear producing districts. In order to make the ethylene preconditioning program commercially feasible for the pear industry, further study has been designed to investigate the effects of fruit maturity, minimum preconditioning time, and fruit package on the initiation of ripening potential of 'd'Anjou' fruit by 100 ppm ethylene treatment.

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