Ethylene from 'Bartlett' Pears Promotes Early Ripening of 'd'Anjou' Pears when Packed Together in Modified Atmosphere Bags

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SUMMARY. 'D'Anjou' pears (*Pyrus communis* L.) harvested at commercial maturity and stored in air at 30 °F (−1 °C) for up to 7 weeks were still incapable of ripening normally at 68 °F (20 °C) for 7 days. 'D'Anjou' fruit at this stage were termed as under-chilled fruit. Ziploc bags [1-gal (3.8-L)] perforated with a number of small holes [1/8 inches (0.32 cm) in diameter] were used to pack five 'd'Anjou' pears and five 'Bartlett' pears [a total net weight of 5 ± 0.2 lb (2.3 ± 0.1 kg)]. The mixed fruit packed in the same bags were placed into a room at 68 °F. When under-chilled 'd'Anjou' fruit packed with 'Bartlett' fruit in the bags perforated with 6, 8, or 10 holes, 'Bartlett' fruit became fully ripe after 5 days while 'd'Anjou' fruit were capable of ripening normally after 7 days at 68 °F. Ripened fruit of both pear cultivars developed high dessert quality. The concentration of ethylene in these bags accumulated to ≈50 ppm

(mg·L⁻¹) on day 4 while CO₂ concentration did not increase to above 3% and O₂ concentration maintained at 18%. Ethylene generated naturally by 'Bartlett' pears during ripening at 68 °F and accumulated in the bag perforated with 6 to 10 holes was sufficient to induce the normal ripening activities of under-chilled 'd'Anjou' pears. This packaging technology may be used to promote early marketing for both pear cultivars.

It is well documented that most 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 'd'Anjou' fruit harvested at commercial maturity with flesh firmness (FF) of 14.0 ± 1.0 lb (6.4 ± 0.5 kg) required 60 d of chilling at 30 °F (−1 °C) to induce normal ripening while late-mature fruit [FF <13 lb (5.9 kg)] still required 30 d at 30 °F to ripen normally at 68 °F (20 °C) (Chen and Mellenthin, 1981). A recent study by Kupferman and his coworkers has shown commercially packed 'd'Anjou' pears shipped before November did not soften properly after 7 d of ripening at room temperature (Kupferman, 1994). Therefore, the consumer could not obtain 'd'Anjou' fruit with a desirable eating quality in September or October each year.

A previous report demonstrated ripening of under-chilled 'd'Anjou' pears could be induced by external ethylene treatment (Chen et al., 1996). The method of preconditioning 'd'Anjou' pears involves warming stored fruit to 68 °F for a few days with 100 ppm (mg·L⁻¹) ethylene before shipment. The preconditioned fruit are then cooled to a temperature of 30 °F for further handling and shipping. To be commercially feasible, preconditioned fruit must remain green and firm to avoid bruising during shipping and distributing. In the Pacific Northwest, the commercial harvest period of 'd'Anjou' pears could be extended for as much as 3 weeks in any pear-producing district due to heavy crop load and/or labor shortages. Therefore, it is always potentially risky to precondition late-mature 'd'Anjou' fruit to a point at which they become vulnerable to bruising damage in transit. It would

be preferable to have 'd'Anjou' fruit preconditioned at the production site rather than at the retail market where facilities may be limited and labor costs are often higher. To construct or convert a room specially equipped for preconditioning 'd'Anjou' fruit is quite costly.

Although 70% of green 'Bartlett' pears are used commercially for canning (Washington–Oregon Canning Pear Association, 1994), the total shipment of fresh 'Bartlett' pears in the Pacific Northwest in 1996 was 2.2 million standard boxes [44 lb (20 kg)/box] (Northwest Fresh Bartlett Marketing Committee, 1996 and 1997). About 97% of fresh 'Bartlett' pears are shipped to the retail market before mid-December each year (Northwest Fresh Bartlett Marketing Committee, 1996 and 1997). In most pear growing districts, the commercial harvest date of optimum mature 'Bartlett' pears [FF 19–17 lb (8.6–7.7 kg)] was ≈2 weeks earlier than 'd'Anjou' pears [FF 15–13 lb (6.8–5.9 kg)] (Porritt, 1964). The chilling requirement to induce normal ripening of 'Bartlett' pears is no more than 21 d at 30 °F (Puig et al., 1996). Porritt (1964) reported that 'Bartlett' fruit harvested at late maturity with flesh firmness of 16.7 lb (7.6 kg) required 10 d at 70 °F (21.1 °C) or 13 d at 60 °F (15.6 °C) to soften to 3 lb (1.4 kg) if they had not been exposed to prior cold storage temperature. 'Bartlett' fruit harvested at commercial maturity can generate ethylene as high as 20 (L/lb/h (44 μL·kg⁻¹·h⁻¹) at 68 °F even without exposure to cold storage temperature (Wang et al., 1971). The capability of 'Bartlett' fruit to exhibit autocatalytic ethylene production provides the potential to induce normal ripening of under-chilled 'd'Anjou' pears without using external ethylene. In this report, we demonstrate a simple and practical packaging method for promoting normal ripening of under-chilled 'd'Anjou' pears using ethylene generated naturally by 'Bartlett' pears.

Materials and methods

'Bartlett' pears were harvested at commercial maturity with FF of 18 ± 0.5 lb (8.2 ± 0.2 kg) from an orchard block located at the Mid-Columbia Agricultural Research and Extension Center, Hood River, Ore (MCAREC) on 15 Aug. 1997. Harvested fruit were transferred into wooden boxes [44 lb

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(20 kg)/box] with polyethylene liners and placed in air storage at 30 °F (−1 °C) until use. 'd'Anjou' pears were also harvested at commercial maturity with FF of 14.0 ± 0.6 lb (6.4 ± 0.3 kg) from an orchard block of mature trees located at MCAREC on 2 Sept. 1997. Harvested fruit were transferred into wooden boxes [44 lb (20 kg)/box] with polyethylene liners and held in air storage at 30 °F. After 1 to 2 weeks of storage referring to the harvest date of 'd'Anjou' fruit, five 'd'Anjou' and five 'Bartlett' pears [a total net weight of 5 ± 0.2 lb (2.3 ± 0.1 kg)] were packed in a 1-gal (3.8-L) Ziploc freezer bag perforated with different number of holes [1/8 inches (0.32 cm) in diameter]. The mixed fruit packed in the bags were placed into a room at 68 °F (20 °C) to evaluate ripening activities.

To determine the effect of perforation on ripening activities of 'd'Anjou' fruit, the number of perforations were 2, 4, 6, 8, and 10 holes for different bags. The position of the perforation was 3 inches away from each edge, 3 inches from the bottom, and 2 inches from the top of the bag. By using a 1/8-inch (0.32-cm)-diameter cork borer, the first perforation was made at the bottom left edge, followed by the bottom right edge, the top center, the top left edge and the top right edge of the bag which made up a 2-, 4-, 6-, 8-, and 10-hole bag respectively. Five 'd'Anjou' pears were transferred into the bag first followed by five 'Bartlett' pears. The bag packed with the mixed pears was then zipped.

To determine the effect of storage length on ripening activities of 'd'Anjou' pears, five 'd'Anjou' pears stored for 3, 4, 5, 6, and 7 weeks at 30 °F were packed with five 'Bartlett' pears in a 10-hole bag and then placed into a room at 68 °F. Ethylene concentration in the room increased from 0.1 ppm (mg·L⁻¹) to 0.6 ppm (mg·L⁻¹) in 5 d. As a control, corresponding 10-hole bags packed with five 'd'Anjou' pears were placed into another room at 68 °F. Ethylene concentration in this room was maintained to less than 0.1 ppm (mg·L⁻¹) by continuous ventilation.

For each experiment described above, the concentration of carbon dioxide, oxygen and ethylene in each bag was determined daily for 5 d by gas chromatography (Chen and Mellenthin, 1981; Mellenthin et al.,

1980). Five 'Bartlett' fruit were then removed from the bag on day 5 at 68 °F. Dessert qualities of 'Bartlett' fruit were evaluated organoleptically by the authors and rated on a nine-point hedonic scale (9 = buttery and juicy texture with excellent flavor; 1 = mealy, coarse, and dry texture with off flavor) (Heintz and Kader, 1983; McBride, 1986). An average score of 5 or higher was arbitrarily defined as commercially acceptable. Five 'd'Anjou' fruit packed in the same bag were retained in the bag for 2 more d at 68 °F. Changes in FF, extractable juice (EJ), titratable acids (TA) and soluble solids concentration (SSC) of treated 'd'Anjou' fruit were determined on day 7 at 68 °F by the methods described previously (Chen and Borgic, 1985; Chen and Mellenthin, 1981). Dessert quality of treated 'd'Anjou' fruit were also assessed by the authors using the same scale as for 'Bartlett' pears. The changing pattern of EJ in ripening pears is an objective method for evaluation of texture quality (Chen and Borgic, 1985). When pears are ripening normally, water-soluble polyuronides in the pulp tissues increase dramatically which result in an apparent increase in hygroscopic binding capacity of the ripening pulp tissues (predominantly the cell wall components). The phenomenon is consistent with the reduction of EJ in the ripening pulp tissues, which can be easily measured by a one-speed centrifugal juicer (Chen and Borgic, 1985). The ripened pears with buttery and juicy texture usually have a higher reduction of EJ than those fruit ripened only partially with chewy, coarse and dry texture.

For each experiment, one bag was considered an experimental unit and there were three replications per each treatment.

Results and discussion

EFFECT OF PERFORATION. 'Bartlett' and 'd'Anjou' pears packed in the bag with two or four holes did not develop acceptable dessert quality (scored <4.0) after 5 and 7 d respectively at 68 °F (20 °C) (Fig. 1). The fruit tasted chewy and dry indicating it was not fully ripe. 'Bartlett' and 'd'Anjou' fruit packed in the bag with 6, 8, and 10 holes developed highly desirable dessert quality (scored >7.0) after 5 and 7 d respectively at 68 °F (Fig. 1). The ripened fruit tasted buttery, juicy and flavorful.

Carbon dioxide concentration in

the bag with two holes accumulated rapidly to 9% on day 1 at 68 °F and increased to 13.4% on day 5 (Fig. 2A). Carbon dioxide concentration in the bag with four holes accumulated to 5% on day 1 and increased to 6.4% on day 5 (Fig. 2A). The bags perforated with 6 to 10 holes did not allow the CO₂ concentration to accumulate to above 3% during 5 d at 68 °F (Fig. 2A). Oxygen concentration in the bag perforated with two holes quickly decreased to 8.1% on day 1 at 68 °F and then maintained 7% to 7.5% during the rest of 4 d at 68 °F (Fig. 2B). Oxygen concentrations in the bag with four holes decreased to between 17% and 16% during 5 d at 68 °F (Fig. 2B). The bag perforated with 6 to 10 holes allowed the gas exchange more freely with the ambient air and maintained oxygen concentrations at 18% to 19% during 5 d at 68 °F (Fig. 2B). Ethylene concentrations in the bag perforated with two holes increased constantly from 35 ppm to 122 ppm (mg·L⁻¹)

Fig. 1. Sensory evaluation of overall dessert quality (including texture and flavor) for ripened 'd'Anjou' and 'Bartlett' pears packed together in bags perforated with 2, 4, 6, 8, or 10 holes [1/8 inches (0.32 cm) in diameter]. 'Bartlett' fruit were removed on day 5 of ripening at 68 °F (20 °C) for assessment of dessert quality while 'd'Anjou' fruit were retained in the bags until day 7 before dessert quality assessment. The vertical line on each bar graph represents ± the standard error.

Fig. 2. Changes in carbon dioxide (A), oxygen (B), and ethylene (C) concentrations in bags containing five 'd'Anjou' and five 'Bartlett' fruit and perforated with 2, 4, 6, 8, or 10 holes [1/8 inches (0.32 cm) in diameter] during 5 d of ripening at 68 °F (20 °C) in air. 'D'Anjou' pears had been stored in air at 30 °F (−1 °C) for 1 to 2 weeks before beginning gas analyses. $LSD_{0.05}$ = The least significant difference at the 5% level.

during 5 d at 68 °F while those bags with 4, 6, 8, and 10 holes increased to 84 ppm, 79 ppm and 59 ppm ($\text{mg}\cdot\text{L}^{-1}$) respectively (Fig. 2C).

When 'd'Anjou' fruit had been stored in air at 30 °F for only 2 weeks, its flesh firmness (FF) and its content of extractable juice (EJ) were 15.0 ± 0.4 lb (6.8 ± 0.2 kg) and 69.5 ± 1.5 mL (per 100 g fresh weight) respectively (Data obtained by separate measurements). 'D'Anjou' pears packed with 'Bartlett' fruit in a bag with two or four holes softened partially to 9.8 lb (4.4 kg) and 7.3 lb (3.3 kg) respectively and only reduced the EJ content slightly to 66.0 and 64.8 mL respectively on day 7 at 68 °F (Table 1). The results indicated that 'd'Anjou' fruit in the bags with two or four holes were incapable of developing proper ripeness after 7 d at 68 °F. 'D'Anjou' fruit packed in the bags with 6, 8, and 10 holes softened to proper ripeness with FF of 4.7 ± 0.2 lb (2.1 ± 0.1 kg) and reduced EJ to 59.0 ± 1.0 mL on day 7 at 68 °F (Table 1). Titratable acids (TA) in 'd'Anjou' fruit packed in the bag with different perforations were at ≈ 4.1 milliequivalent (meq)/100 mL juice and were not significantly different among the treatments (Table 1). Soluble solids content (SSC) in 'd'Anjou' pears packed in a two-hole bag was 11.7%, which was significantly lower than SSC in those fruit packed in the bag with 4- to 10-hole perforations (ranging between 12.3% and 12.7%) (Table 1).

Ethylene generated by 'Bartlett' pears and accumulated in the bag with 6- to 10-hole perforations during 5 d at 68 °F was sufficient to induce normal ripening activities of 'd'Anjou' pears packed in the same bag. For ethylene to be effective, carbon dioxide concentration in the bag should

not accumulate to above 3% while oxygen concentration did not deplete to below 18%. Burg and Burg (1969) proposed that fruit ripening was initiated by ethylene molecules binding to metal-containing receptors, which were competitively inhibited by CO_2 molecules. Oxygen was required for ethylene action during the ripening process (Burg and Burg, 1969; Pech et al., 1994). The antagonistic effect of carbon dioxide on ethylene-induced physiological responses has been demonstrated in other plant tissues (Burg and Burg, 1967; Kang et al., 1967). In this study, the accumulation of CO_2 above 5% and depletion of O_2 below 18% in the bag perforated with two and four holes undoubtedly inhibited ethylene action and, therefore, delayed the onset of ripening processes of pears.

EFFECT OF STORAGE LENGTH. Carbon dioxide concentrations in the 10-hole bag accumulated gradually from 1.7% on day 1 to 3% on day 5 at 68 °F regardless of prior length of storage of mixed pears (Fig. 3A). Oxygen concentrations in the 10-hole bag remained at 18% or higher during 5 d at 68 °F irrespective of storage length (Fig. 3B). Similarly, ethylene concentrations in the 10-hole bag increased from 20 ppm ($\text{mg}\cdot\text{L}^{-1}$) on day 1 to 50 ppm ($\text{mg}\cdot\text{L}^{-1}$) or higher on day 5 at 68 °F (Fig. 3C).

During 7 weeks of storage in air at 30 °F, 'd'Anjou' pears packed alone in a 10-hole bag were incapable of ripening after 7 d at 68 °F. Fruit remained firm at 15 lb (6.8 kg) and maintained EJ at no less than 68.0 mL per 100 g fresh weight (Table 2). Ethylene concentration in the bag was below 0.1 ppm ($\text{mg}\cdot\text{L}^{-1}$), oxygen concentration was 20.5% and carbon dioxide concentration never accumulated to over

Table 1. Flesh firmness (FF), extractable juice (EJ), titratable acids (TA), and soluble solids concentration (SSC) in 'd'Anjou' pears packed with the same number of 'Bartlett' pears in 1-gal Ziploc freezer bag perforated with 2, 4, 6, 8, and 10 holes [1/8 inches (0.32 cm) in diameter]. The bags packed with pears were held in air at 68 °F (20 °C) and 'Bartlett' fruit were removed from each bag on day 5. FF, EJ, TA and SSC in 'd'Anjou' fruit were assessed on day 7 at 68 °F (20 °C).

Perforation (no. of holes)	FF [lb (kg)]	EJ (mL/100 g)	TA (meq/100 mL)	SSC (%)
2	9.8 (4.4)	66.3	4.5	11.7
4	7.3 (3.3)	64.8	4.1	12.3
6	4.9 (2.2)	59.1	3.9	12.6
8	4.9 (2.2)	59.8	4.0	12.6
10	4.6 (2.1)	58.0	4.1	12.7
$LSD_{0.05}$	0.7***	2.8***	0.5 ^{ns}	0.4**

^{ns}, **, *** Nonsignificant or significant at $P \leq 0.01$ or 0.001, respectively.

Fig. 3. Changes in carbon dioxide (A), oxygen (B), and ethylene (C) concentrations in bags perforated with 10 holes [1/8 inches (0.32 cm) in diameter] and packed with five 'd'Anjou' fruit and five 'Bartlett' fruit during 5 d of ripening at 68 °F (20 °C) in air. 'D'Anjou' pears had been stored in air at 30 °F (−1 °C) for 3, 4, 5, 6 and 7 weeks. $LSD_{0.05}$ = The least significant difference at the 5% level.

0.5% during 7 d at 68 °F. These data indicate that 'd'Anjou' pears stored for 7 weeks at 30 °F were still under chilled and incapable of generating threshold amounts of ethylene to induce autocatalytic ethylene biosynthesis for normal ripening (Blankenship and Richardson, 1985). When under-chilled 'd'Anjou' pears packed with an equal number of 'Bartlett' pears in the 10-hole bag, they softened normally after 7 d at 68 °F with a reduction of EJ to 58 mL/100 g fresh weight or lower (Table 2). TA in 'd'Anjou' fruit packed alone or with 'Bartlett' fruit decreased gradually from 3 to 7 weeks of storage (Table 2) which was a typical phenomenon of 'd'Anjou' pears during storage (Chen and Mellenthin, 1981). SSC in 'd'Anjou' fruit packed with 'Bartlett' pears was $\approx 0.3\%$ higher than SSC in 'd'Anjou' fruit packed alone (Table 2).

When 'Bartlett' fruit were partially removed from the bag of mixed fruit at two fruit per day from day 4 to day 6 of ripening at 68 °F, 'd'Anjou' pears continued to ripen and softened to 5.0 lb (2.3 kg), 3.5 lb (1.6 kg), and 2.5 lb (1.1 kg) with juicy and buttery texture on day 7, 8 and 9 respectively at 68 °F (Data obtained by separate measurements). Thus, an equal number of 'Bartlett' and 'd'Anjou' pears packed in either a 5- or 6-lb (2.3- or 2.7-kg) bag would be ready to eat within 6 d after the 'Bartlett' skin color had turned yellow after 4 d of ripening at 68 °F. It would not be necessary for the consumer to know the exact days of ripening of 'Bartlett' fruit since changes in skin color from green to yellow would be the indicator of properly ripening. Since 'd'Anjou' pears do not change skin color as markedly, it would be easy for the consumer to enjoy fully ripened 'd'Anjou' pears after finishing consuming ripened 'Bartlett' fruit packed in the same bag.

The position of perforation on the bag was important in that pears packed in the bag would not block the holes for proper gas exchange. The size and number of perforation was also important allowing ethylene generated by 'Bartlett' fruit to accumulate to a sufficient level of 50 ppm ($\text{mg}\cdot\text{L}^{-1}$) or

Table 2. Flesh firmness (FF), extractable juice (EJ), titratable acids (TA), and soluble solids concentration (SSC) in 'd'Anjou' pears packed with or without (control treatment) the same number of 'Bartlett' pears in 1-gal Ziploc freezer bag perforated with 10 holes [1/8 inches (0.32 cm) in diameter]. The bags packed with pears were held in air at 68 °F (20 °C) and 'Bartlett' fruit were removed from each bag on day 5. FF, EJ, TA, and SSC in 'd'Anjou' fruit were assessed on day 7 at 68 °F (20 °C). 'D'Anjou' pears had been stored in air at 30 °F (−1 °C) for 3, 4, 5, 6, and 7 weeks while 'Bartlett' pears stored for 5, 6, 7, 8, and 9 weeks for each experiment.

Packaging treatment ^y	Storage interval ^z (weeks)	FF [lb (kg)]	EJ (mL/100 g)	TA (meq/100 mL)	SSC (%)
A + B	3	5.2 (2.4)	60.0	4.3	12.4
	4	5.2 (2.4)	59.2	4.3	12.7
	5	5.1 (2.3)	58.0	4.0	12.5
	6	4.6 (2.1)	58.3	3.9	12.5
	7	4.7 (2.1)	59.1	4.0	12.7
A	3	14.8 (6.7)	68.6	4.4	12.1
	4	14.8 (6.7)	68.8	4.3	11.9
	5	14.7 (6.7)	69.1	4.1	12.2
	6	14.7 (6.7)	69.1	4.0	12.0
	7	14.6 (6.6)	67.9	4.0	11.8
$LSD_{0.05}$		0.4 (0.2)	1.7	0.2	0.4
Sources	df	Significance			
Treatment (T)	1	**	**	NS	**
Storage (S)	4	NS	NS	*	NS
T × S	4	NS	NS	NS	NS

^zStorage interval refers to the length in weeks of 'd'Anjou' pears stored at 30 °F (−1 °C) in air.

^yA + B refers to the bag packed with 'd'Anjou' and 'Bartlett' pears. A refers to the bag packed with 'd'Anjou' pears only as control treatment.

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

greater on day 4 at 68 °F to induce normal ripening of 'd'Anjou' pears. In addition, carbon dioxide produced by the fruit did not accumulate to an inhibitory level (>3%) for normal ripening process of either cultivar. Oxygen in the external air should be able to diffuse rather freely into the perforated bag to make up the loss during respiration and to maintain a level no less than 18%.

Conclusion

The perforated bag designed commercially for packaging 'Bartlett' pears has 24 holes with 1/8 inches (0.32 cm) diameter per each hole. The perforations start 4 inches (10.2 cm) away from the bottom and 3.5 inches (8.9 cm) away from each edge of the bag. There are two rows (six holes per row) on each side of the bag. The distance between each hole is 1.5 inches (3.8 cm). The bag is designed to pack 6 lb (2.7 kg) of 'Bartlett' pears. The number of perforation on this bag can be easily reduced in half from each side so that the modified bag can be used to pack the mixture of 'd'Anjou' and 'Bartlett' pears.

The advantages of using ethylene generated naturally by 'Bartlett' pears to promote normal ripening activities of under-chilled 'd'Anjou' pears packed in the same perforated bag are as follows:

- 1) Packing houses do not need to construct a special room for preconditioning under-chilled 'd'Anjou' pears during early marketing season.
- 2) Existing packaging lines for 'Bartlett' pears in any packing house could be used for packaging the mixture of 'd'Anjou' and 'Bartlett' pears. The first line could be used for inserting 'd'Anjou' pears into the bottom half of the bag and the second line for inserting an equal number of 'Bartlett' fruit on top. The net weight of fruit per bag could be between 5 and 6 lb (2.3 to 2.7 kg).
- 3) Since 'Bartlett' pears ripened with desirable dessert quality ≈2 d ahead of

'd'Anjou' fruit, a household could consume a 6-lb (2.7-kg) bag of mixed fruit within 6 d. The consumer could enjoy eating 'Bartlett' fruit first when the skin color of 'Bartlett' fruit had turned yellow after 4 d of display on the fruit shelf at ambient room temperature.

Ethylene generated by ripening 'Bartlett' pears not only promotes normal ripening of under-chilled 'd'Anjou' pears packed in the same 10-hole bag, but may also improve early marketing of both pear cultivars.

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