Ripening Behavior of 'Columbia' and 'Gebhard' Strains of Red 'd'Anjou' Pears after Cold Storage

Paul M. Chen, Diane M. Varga, and Eugene A. Mielke

Mid-Columbia Agricultural Research and Extension Center, Oregon State University, 3005 Experiment Station Drive, Hood River, OR 97031

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Abstract. 'Columbia' and 'Gebhard' strains of red 'd'Anjou' pears (*Pyrus Communis* L.) harvested at similar maturity exhibited different ripening behavior after monthly removal from 1C storage in air. 'Columbia' fruit produced ethylene at higher rates than 'Gebhard' fruit during 15 days of ripening at 20C after each corresponding storage interval, 'Gebhard' fruit required a longer period of chilling than 'Columbia' fruit to generate noticeable rates of ethylene during ripening. The unripened fruit of both strains contained similar amounts of ACC at each corresponding storage interval. At each corresponding ripened state, ACC content in 'Columbia' fruit increased 2 to 3-fold, while that in 'Gebhard' fruit changed very little. After sufficient chilling, 'Columbia' fruit were capable of softening to proper ripeness, and they developed buttery and juicy texture as indicated by the apparent reduction of extractable juice (EJ) content. 'Gebhard' fruit also softened but to a lesser extent than 'Columbia' fruit. Ripened 'Gebhard' fruit had only slightly lower levels of EJ than unripened fruit and did not develop a buttery and juicy texture after any storage intervals. Titratable acidity (TA) in fruit of both strains varied between for the 1988 and 1989 seasons but decreased significantly during storage in both years. Soluble solids concentrations (SSC) in both strains also varied seasonally but did not change during storage or ripening. Chemical name used: 1-aminocyclopropane-1-carboxylic acid (ACC).

Red 'd'Anjou' pear fruit were developed from a bud sport (periclinal chimera) of green 'd'Anjou' trees. Red 'd'Anjou' fruit are highly profitable in fresh markets due to their attractive bright red skin. There are two strains of red 'd'Anjou' pear trees that have been commercially propagated and planted in the Pacific Northwest of the United States. The 'Gebhard' strain, which originated from the Medford district of Oregon, has been commercially grown for ~20 years, while the 'Columbia' strain, a new patented strain from the Hood River district of Oregon, has been widely planted since 1980.

Preliminary study has shown that the ripening behavior of these two red strains is quite different after a sufficient period of postharvest chilling. The 'Columbia' strain ripens similarly to green 'd'Anjou' fruit. The 'Gebhard' strain does not soften properly or undergo the normal climacteric process. The objective of this study was to describe ripening characteristics of 'Columbia' and 'Gebhard' red 'd'Anjou' pears after various durations of cold storage in an attempt to reveal the basic physiological differences between these two strains.

Materials and Methods

Both 'Gebhard' and 'Columbia' strains of red 'd'Anjou' pear fruit were obtained from 10-year-old trees on identical rootstock (Old Home x Farmingdale 333) grown in an orchard block at the Mid-Columbia Agricultural Research and Extension Center, Hood River, Ore., in 1988 and 1989. 'Gebhard' fruit reached harvest maturity about one week later than 'Columbia' fruit as indicated by the flesh firmness (FF). Fruit were harvested when the FF had declined to between 65 and 67 N in 1988 and between 58 and 58.5 N in 1989 (Table 1).

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Nine trees of each strain were divided into three groups. All fruit from each tree were picked and the harvested fruit from each group of three trees were uniformly mixed. All fruit from each group were further divided into 50-fruit lots and stored in wooden boxes with perforated polyethylene liners at -1C in air. Each group of fruit was considered as one replication and each box as an experimental unit. After 1,2,3,4, or 5 months of storage, one box of 50 fruit per replication per strain was removed from cold storage and placed in a ripening room at 20C. The ethylene concentration in the ripening room was kept below 0.1 $\mu\text{l}\cdot\text{liter}^{-1}$ by constant ventilation. The relative humidity in the ripening room was between 60% and 70%. Fruit in each box were covered with four pieces of wet paper towel to reduce moisture loss during ripening.

At the start of each ripening interval, 10 fruits were selected from each box, weighed, and transferred into a 10-l plexiglass ripening chamber. Each ripening chamber had inlet and outlet tubes and an air-tight lid. The temperature in the chamber was maintained at 20C ($\pm 0.5\text{C}$). Relative humidity was not controlled or monitored. Ethylene-free air was passed into the inlet tube into each chamber at a constant flow of 200 $\text{ml}\cdot\text{min}^{-1}$. Fruit ethylene production in each chamber was measured daily for 15 days by a gas chromatography with the detection limit of 0.001 $\mu\text{l}\cdot\text{liter}^{-1}$ (Chen and Mellenthin, 1981).

In 1989, another five fruit from each box (experimental unit) on day 1 and day 8 of ripening were used for the preparation of 80% ethanol extract for ACC analysis. Detailed methods for preparing the ethanol extract were described by Mellenthin et al. (1980). Fifty milliliters of the ethanol extract (equivalent to 1 g freeze-dried weight) from each experimental unit was evaporated to complete dryness at 60C, and the residue was dissolved in 10 ml of distilled water. The 10-ml aliquot was passed through a Bio-Rad poly-prep chromatography column packed with 0.5 g insoluble polyvinylpyrrolidone to absorb phenolic compounds. The clear aliquot (1 ml) was assayed for ACC according to the modified method of Coleman and Hodges (1991).

Abbreviations: EJ, extractable juice; FF, flesh firmness; SSC, soluble solids concentration; TA, titratable acidity.

Table 1. Harvest date and maturity indices at harvest of 'Columbia' and 'Gebhard' strains of red 'd'Anjou' pears in 1988 and 1989.

Year	Date (September)	Strain	FF (N)	TA (meq/100 ml)	SSC (%)
1988	12	Columbia	64.9 ± 4.4x	4.9 ± 0.6x	14.2 ± 0.4x
	19	Gebhard	66.7 ± 2.5	4.1 ± 0.6	14.1 ± 0.4
1989	7	Columbia	58.0 ± 4.5	6.8 ± 0.5	13.5 ± 0.3
	16	Gebhard	58.5 ± 2.9	6.2 ± 0.3	13.9 ± 0.4

X = ±SD.

In 1988 and 1989, 10 fruit per box from each replicate were used for the determination of FF, EJ, TA, and SSC on day 1 (unripened fruit) and day 8 of ripening (ripened fruit) after each storage interval. FF was measured with an Instron Universal Testing Instrument Model 1000 (Canton, Mass.) equipped with a 45.37 kg weigh beam and an S-mm plunger. Two pared spots located on opposite sides of a fruit sector perpendicular to the most sun-exposed area were penetrated to a depth of 9 mm with a constant speed of 100 mm·min⁻¹. The FF readings from the Instron were in pound force, which was converted into Newton. After measurement of FF, the same fruit were used for the assessments of EJ, TA, and SSC according to documented methods (Chen and Borgic, 1985; Chen and Mellenthin, 1981; Chen et al., 1981).

Five additional ripened fruits from each replication on day 8 of ripening were used for the assessment of texture quality by three experienced panelists. Texture quality was scored on a 5-point hedonic rating scale (Cloninger and Baldwin, 1976). Ripened fruit with highly, moderately, and slightly buttery and juicy flesh texture were rated as 5, 4, and 3, respectively, and those with either moderately and very firm (i.e., underripe fruit) or moderately and very mealy (i.e., overripe fruit) flesh texture were rated as 2 and 1, respectively.

Results and Discussion

'Gebhard' matured -1 week later than 'Columbia' in both years, according to the maturity index of FF, which was between 57.8 and 66.7 N (Table 1) (Hansen and Mellenthin, 1979). Fruit harvested in 1989 were -7 N softer than those harvested in 1988 but were still within the range of optimum maturity. Although fruit harvested in 1988 were firmer than those in 1989, TA levels in fruit of both strains in 1988 were much lower than those in 1989, while SSC levels were similar in both years (Table 1). FF has been the most reliable and seasonally consistent method for determining harvest maturity for all pear varieties (except Asian pears), while other indices such as TA and SSC are quite inconsistent from season to season (Hansen and Mellenthin, 1979). FF was used as the sole maturity index for the determination of harvest dates of 'Columbia' and 'Gebhard' strains of red 'd'Anjou' pears in this study.

The combined 2 years of data of ethylene production were used for plotting ethylene climacteric curves (Watada et al., 1984). 'Columbia' fruit produced measurable rates of ethylene production during ripening following 1 and 2 months of storage but did not reach a peak in 15 days of ripening (Fig. 1). The rates of ethylene production in 'Columbia' fruit increased appreciably during 15 days of ripening following 3, 4, and 5 months of storage and peaked on days 14, 10, and 10, respectively. 'Gebhard' fruit, however, did not produce detectable rates of ethylene during ripening until after 3 months of storage and did not show an ethylene peak during ripening until after 5 months of storage (Fig. 1). At any corresponding storage intervals, 'Columbia' fruit always

produced much higher rates of ethylene than 'Gebhard' fruit during ripening (Fig. 1). Most winter pears require a period of chilling to exhibit the characteristic climacteric pattern when transferred to a ripening environment at 15 or 20°C (Chen et al., 1982; Chen et al., 1983a; Ulrich and Paulin, 1954). It was evident that 'Columbia' required a shorter period of postharvest chilling than 'Gebhard' for the development of normal ethylene production patterns.

ACC concentrations in the unripened fruit of both strains were similar at each corresponding storage interval and increased rather gradually during 5 months of storage (Table 2). At each corresponding ripened state, ACC concentrations in 'Columbia' fruit increased 2- to 3-fold during ripening, while those in 'Gebhard'

Fig. 1. Changes in ethylene production of 'Columbia' and 'Gebhard' strains of red 'd'Anjou' pears during 15 days of ripening at 20°C after storage for 1 to 5 months at -1°C in air.

Table 2. Changes in ACC in unripened (–) and ripened (+) pulp tissues of 'Columbia' and 'Gebhard' strains of red 'd'Anjou' pears after monthly storage intervals in 1989.

Month(s) of storage	State of ripeness	ACC (nmole·g ⁻¹ dry wt)	
		'Columbia'	'Gebhard'
1	–	1.31	1.29
	+	3.06	1.33
2	–	1.78	1.82
	+	4.66	2.34
3	–	1.97	1.60
	+	6.06	1.99
4	–	2.52	1.97
	+	6.30	1.96
5	–	2.93	2.24
	+	6.08	2.76
LSD 0.05		1.16	
Sources	df	Significance	
Strains	1	***	
Ripemess	1	***	
Months	4	***	

***Significant at $P < 0.001$, according to F test.

fruit changed very little (Table 2). It was apparent that the biosynthetic rate of ACC in 'Gebhard' fruit could not be accelerated by the ripening environment. ACC concentrations in the pulp of green 'd'Anjou' pears were reported to be 2.6 nmol·g⁻¹ fresh weight (i.e., 17.3 nmol·g⁻¹ dried weight assuming the moisture content in the pulp tissues was 85%) after 78 days of storage in air at -1C in 1984 (Blankenship and Richardson, 1985), but only 0.1 nmol·g⁻¹ fresh weight (i.e., 0.7 nmol·g⁻¹ dried weight) after 153 days of storage in 1985 (Blankenship and Richardson, 1986). ACC concentrations in the two strains of red 'd'Anjou' fruit (Table 2) were within the range of ACC concentrations found in regular green 'd'Anjou' fruit.

'Gebhard' fruit generated much lower rates of ethylene than 'Columbia' fruit during each corresponding ripening period (Fig. 1), presumably due to the low biosynthetic rate of ACC in this strain during ripening. Our separate study (unpublished) revealed that the normal ripening capacity of 'Gebhard' fruit could be induced by an application of 100 µl·liter⁻¹ ethylene into the ripening environment. This finding indicates that the low level of

ethylene generated by 'Gebhard' during ripening is insufficient to induce and achieve complete ripening reactions. Blankenship and Richardson (1985) reported that regular green 'd'Anjou' pears required 46 days chilling at -1C to stimulate ethylene biosynthesis and to generate a detectable ACC level. They also demonstrated that green 'd'Anjou' fruit with insufficient chilling (i.e., 30 days at -1C) needed to be kept at 20C in the presence of 50 µl exogenous ethylene/liter during 12 days of ripening for the induction of normal respiratory climacteric.

The difference in the capability of 'Columbia' and 'Gebhard' to generate ethylene during ripening also is reflected in other physiological aspects of ripening. In 1988, 'Columbia' fruit were capable of softening to 23.7 N upon ripening following 1 month of storage. Thereafter, 'Columbia' fruit ripened to between 15.5 and 8.3 N, even after 5 months of storage (Table 3). The proper softening of ripened 'Columbia' fruit coincided with the drastic reduction of EJ to 60 ml/100 g fresh weight or lower (Table 3), as well as the development of high textural quality (Table 4). The apparent reduction of EJ in the ripened pear pulp has been attributed to the solubilization of polyuronides from the cell wall, which causes the marked increase in hygroscopic binding capacity of the pulp tissues upon ripening (Chen and Borgic, 1985). Ripened pulp tissues with strong hygroscopic binding capacity are capable of retaining much juice and, therefore, develop a buttery and juicy texture (Chen et al., 1981; Chen et al., 1983a; Chen et al., 1983b). 'Gebhard' fruit softened very little during holding at 20C for 1 month; thereafter, it softened to no less than 29 N on day 8 of ripening at 20C, even after 4 months of storage (Table 3). While 'Gebhard' fruit softened to 18 N upon ripening following 5 months of storage, the reduction in EJ was minimal (Table 3). These results indicated that 'Gebhard' fruit did not ripen normally after storage, and ripened fruit did not develop buttery and juicy texture regardless of storage period (Table 4).

In 1989, the pattern of softening of the fruit and the reduction of EJ upon ripening after storage were similar to those in 1988 for both strains, except that 'Columbia' fruit required 2 months of chilling for the development of normal ripening capacity as expressed by texture (Table 5). The physiological basis for this seasonal difference was not understood. Ripened 'Columbia' fruit with low EJ were always rated high in texture quality (Table 4). None of ripened 'Gebhard' fruit developed high textural quality regardless of storage period (Table 4).

There were no differences in TA between 'Columbia' and 'Gebhard' strains and between unripened and ripened fruit in 1988

Table 3. Changes in FF and EJ in unripened (–) and ripened (+) pulp tissues of 'Columbia' (Col.) and 'Gebhard' (Geb.) strains of red 'd'Anjou' pears after monthly storage intervals in 1988 and 1989.

Month(s) of storage	State of ripeness	1988				1989			
		FF (N)		EJ (ml/100 g fresh wt)		FF (N)		EJ (ml/100 g fresh wt)	
		Col.	Geb.	Col.	Geb.	Col.	Geb.	Col.	Geb.
1	–	57.8 ± 1.1 ^z	57.0 ± 1.4	70.7 ± 0.7	71.2 ± 0.2	53.0 ± 0.7	53.1 ± 1.2	71.2 ± 0.2	69.2 ± 0.5
	+	23.7 ± 1.8	52.3 ± 1.2	60.0 ± 0.9	68.5 ± 1.7	45.7 ± 1.5	42.5 ± 1.3	65.8 ± 0.6	65.2 ± 0.8
2	–	54.6 ± 1.1	57.9 ± 1.3	71.3 ± 0.9	71.8 ± 0.5	53.7 ± 0.9	52.0 ± 1.1	71.8 ± 0.6	70.3 ± 0.2
	+	15.5 ± 1.8	37.2 ± 3.9	57.7 ± 0.7	68.0 ± 0.6	22.9 ± 0.8	33.0 ± 1.0	60.8 ± 0.5	65.3 ± 0.7
3	–	54.3 ± 1.4	55.8 ± 1.6	71.8 ± 0.5	71.5 ± 0.8	51.3 ± 0.9	50.0 ± 0.9	70.6 ± 0.5	70.3 ± 0.5
	+	8.3 ± 0.2	28.8 ± 1.5	55.0 ± 0.6	66.0 ± 1.2	15.8 ± 0.4	31.0 ± 0.9	56.0 ± 1.0	64.7 ± 0.3
4	–	41.3 ± 0.9	48.0 ± 0.3	70.7 ± 0.9	71.7 ± 0.7	45.0 ± 1.4	46.9 ± 0.6	70.0 ± 0	70.8 ± 0.3
	+	10.9 ± 0.3	29.2 ± 1.3	58.0 ± 0	69.3 ± 0.7	15.7 ± 1.4	31.2 ± 0.7	52.5 ± 0.8	66.8 ± 0.9
5	–	35.9 ± 0.7	43.5 ± 0.2	69.5 ± 0.8	71.3 ± 0.5	35.5 ± 1.7	42.6 ± 0.7	69.0 ± 0.6	69.0 ± 0.6
	+	10.5 ± 0.6	18.4 ± 1.9	58.7 ± 0.9	68.3 ± 1.6	11.6 ± 0.6	27.7 ± 1.2	56.8 ± 0.9	66.2 ± 0.2

^zNo analysis of variance for data sets of FF and EJ were performed due to the heterogeneity of errors. Each data represent a sample means ± SE.

(Table 5). There was a decrease in TA during 5 months of storage in 1988 for both strains (Table 5). SSC in 'Columbia' was significantly higher than that in 'Gebhard' but did not change during storage or upon ripening in 1988 (Table 5).

In 1989, TA in 'Columbia' was higher than in 'Gebhard' during the entire storage period (Table 5). There were no significant differences in TA between unripened and ripened fruit for either strain at each storage interval, but TA in both strains also decreased consistently during storage (Table 5). Unlike in 1988, SSC levels in 'Gebhard' fruit were higher than those in 'Columbia' fruit (Table 5). As in 1988, SSC in either strain did not change during

storage or upon ripening. The results confirmed that TA and SSC in pear fruit fluctuated from season to season and were not reliable maturity indices.

This study shows that ripening of winter pears involves many independent chemical changes that are not completely correlated with each other but occur more or less in parallel to the climacteric pattern (Chen et al., 1983a; Janes and Frenkel, 1978). 'Columbia' fruit ripening was closely associated with the onset of rapid ethylene production and became buttery and juicy. However, the abnormal ripening of 'Gebhard' fruit did not coincide with the pattern of ethylene production. For example, fruit stored for 5 months showed a clear rise in ethylene production during ripening and softened properly upon ripening, but failed to become buttery and juicy, as indicated by only a slight reduction of EJ and low textural quality rating. Pratt and Goeschl (1969) classified the role of ethylene in fruit ripening into two separate phenomena: the initial ethylene generated by fruit as the "trigger" of ripening and the excess ethylene production that accompanies ripening, climacteric, and final senescence. We propose that 'Gebhard' fruit might be incapable of generating sufficient amounts of "trigger" ethylene to carry out a complete ripening process.

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Table 4. Sensory ratings of textural quality of ripened 'Columbia' and 'Gebhard' strains of red 'd'Anjou' pears after monthly storage intervals. "5" = buttery and juicy; "1" = firm (underripe fruit) or mealy and dry (overripe fruit).

Months of storage	Strains	Textural quality scores	
		1988	1989
1	Columbia	2.8	1.9
	Gebhard	1.5	1.5
2	Columbia	3.5	2.9
	Gebhard	1.6	1.6
3	Columbia	4.1	3.7
	Gebhard	2.0	2.5
4	Columbia	3.9	4.1
	Gebhard	1.8	2.1
5	Columbia	2.9	3.7
	Gebhard	1.7	1.8
LSD 0.05		0.3	
Source		df	Significance
Year		1	NS
Strains		1	***
Months		4	***

***Significant at $P < 0.001$ according to F test. NS = nonsignificant at $P < 0.05$.

Table 5. Changes in TA and SSC in unripened (–) and ripened (+) pulp tissues of 'Columbia' (Col.) and 'Gebhard' (Geb.) strains of red 'd'Anjou' pears after monthly storage intervals in 1988 and 1989.

Month(s) of storage	State of ripeness	1988				1989				
		TA (meq/100 ml)		SSC (%)		TA (meq/100 ml)		SSC (%)		
		Col.	Geb.	Col.	Geb.	Col.	Geb.	Col.	Geb.	
1	—	4.3	4.1	14.9	14.2	5.2	4.7	14.2	14.8	
	+	3.9	3.8	15.0	14.7	5.5	4.5	14.4	15.0	
2	—	3.6	3.5	14.8	14.4	5.1	4.6	14.2	14.8	
	+	3.8	3.5	15.3	14.6	4.6	4.4	14.2	15.2	
3	—	3.2	3.3	14.9	14.1	4.3	3.9	14.2	14.8	
	+	3.2	3.4	15.5	14.4	4.4	3.9	14.3	15.1	
4	—	3.1	2.7	14.7	14.4	3.6	3.4	14.4	14.7	
	+	2.8	2.7	14.9	14.6	3.5	3.7	14.2	14.8	
5	—	2.6	2.1	15.0	14.6	3.2	2.9	14.4	14.7	
	+	2.4	2.1	14.9	14.6	3.0	3.0	14.1	15.1	
LSD 0.05		2.5		2.6		0.7		0.5		
Sources		df	TA		SSC		TA		SSC	
Strain		1	NS		***		**		***	
Ripeness		1	NS		NS		NS		NS	
Months		4	***		NS		***		NS	

*, ***, Significant at $P < 0.01$ and 0.001 , respectively, according to F test. NS = nonsignificant at $P < 0.05$.

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