

# Quality Changes in Fresh-cut Pear Slices as Affected by Cultivar, Ripeness Stage, Fruit Size, and Storage Regime

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**ABSTRACT:** Fresh-cut fruit slices prepared from partially ripened Bartlett pears had longer shelf life than those from Bosc, Anjou, and Red Anjou pears. Pear fruit ripeness, based on flesh firmness of 44 to 58 N, is optimal for fresh-cut pear slice processing. Pear slices derived from smaller size fruit (122 to 135 g) have greater cut surface discoloration and deteriorate more rapidly than slices derived from larger fruit (152 g). Recently harvested Bartlett pear fruit and whole pears held at  $-1\text{ }^{\circ}\text{C}$  in a controlled atmosphere of  $2\%\text{O}_2 + 98\%\text{N}_2$  had a longer post-cutting shelf life than those held in air at  $-1\text{ }^{\circ}\text{C}$  for the same duration. Cut surface browning, flesh softening, and surface dehydration of the slice cut surface were all contributors to loss of product quality.

**Key Words:** browning, controlled atmosphere, minimal processing, pear, storage

## Introduction

RECENTLY, SOME FRESH-CUT FRUIT PRODUCTS INCLUDING APPLES, peaches, nectarines, and strawberries, have been marketed for both retail and foodservice distribution. Although fresh-cut pear slices have not been produced commercially, fruit marketers have shown an interest in developing such a product. Important factors that affect the shelf life of fresh-cut fruit products include cultivar, stage of ripeness at cutting, storage atmosphere, and temperature (Gorny and Kader 1996; Gorny and others 1998ab; Gorny and others 1999; Sapers and Miller 1998). Cultivar selection is probably the most important consideration in fresh-cut fruit processing because cultivars can vary greatly in characteristics such as flesh texture, skin color, and browning potential (Amiot and others 1995).

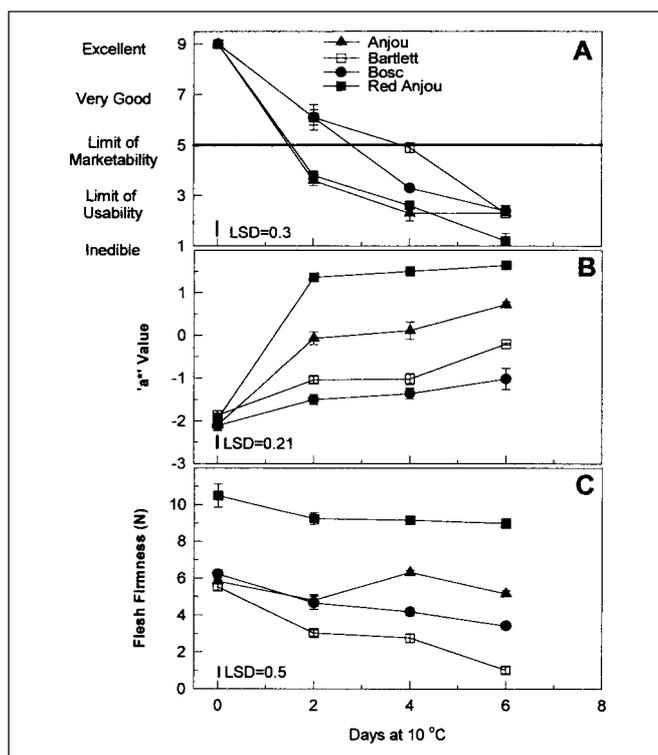
Fresh-cut fruit products are more difficult to produce than fresh-cut vegetable products due to the fact that some fruits must be ripened before they are processed (Gorny and Kader 1996). This is an important issue, since the eating quality and shelf life of fresh-cut fruit products are influenced by the stage of ripeness at cutting (Gorny and others 1998b). The supply scenario of source ingredients for fresh-cut fruit processing is also very different from that of most fresh-cut vegetables. Apples and pears may be stored for many mo at low temperature with or without atmospheric modification before processing. The effect of such storage of intact fruits on the subsequent shelf life of the fresh-cut fruit slices is unknown.

Our objectives were to investigate genotypic differences in shelf life of pear slices derived from 4 cultivars (Bartlett, Bosc, Anjou, and Red Anjou) and to determine respiration and ethylene ( $\text{C}_2\text{H}_4$ ) production rates to gather information that could be used in designing modified atmosphere packaging systems. We also report on the effects of ripeness stage at cutting, whole fruit size, and long-term air and controlled atmosphere storage at  $-1\text{ }^{\circ}\text{C}$  before cutting on the shelf life of fresh-cut pear slices.

## Results and Discussion

### Cultivars and production areas

Bosc and Bartlett pear slices had the longer shelf life, of 3 and 4 d, respectively, while Anjou and Red Anjou pear



**Fig. 1**—Cultivar differences in shelf life of fresh-cut pear slices based on (A) the number of days to deteriorate to a visual quality score of 5 (limit of marketability), (B) cut surface browning intensity ( $a^*$  value), and (C) flesh firmness. Bartlett, Bosc, and Anjou pear fruit were ripened to 27 to 45 N firmness, and Red Anjou were ripened to  $65 \pm 8.9$  N firmness, cut, and then kept in air at  $10\text{ }^{\circ}\text{C}$  and 90% to 95% relative humidity. Data shown are the means ( $\pm$  standard deviation) of 3 replicates. Vertical bar = pooled LSD at the 5% level.

slices became unmarketable in less than 2 d at  $10\text{ }^{\circ}\text{C}$  (Fig 1A). Pear slice shelf life was closely correlated with the incidence of cut surface browning (Fig. 1B). Slices from Anjou and Red Anjou pears exhibited the most intense enzymatic browning among

**Table 1—Range of CO<sub>2</sub> and C<sub>2</sub>H<sub>4</sub> production rates of pear slices during 3 d of storage at indicated temperatures**

Cultivar	Respiration rate <sup>z</sup> (nmol CO <sub>2</sub> C kg <sup>-1</sup> C s <sup>-1</sup> )			Q <sub>10</sub> (0 to 10 °C)	C <sub>2</sub> H <sub>4</sub> production rate <sup>y</sup> (pmol C kg <sup>-1</sup> C s <sup>-1</sup> )			Q <sub>10</sub> (0 to 10 °C)
	0 °C	10 °C	20 °C		0 °C	10 °C	20 °C	
Anjou	41 to 94	156 to 183	497 to 771	1.9 to 3.8	14 to 25	92 to 113	138 to 971	4.5 to 6.6
Bartlett	69 to 120	242 to 289	779 to 893	2.4 to 3.5	97 to 272	634 to 859	269 to 1416	3.2 to 6.5
Bosc	41 to 65	179 to 191	501 to 893	2.9 to 4.4	41 to 115	397 to 473	1071 to 1223	4.1 to 9.7
Red Anjou	42 to 108	148 to 198	471 to 677	1.8 to 3.5	8 to 11	64 to 82	104 to 890	7.5 to 8.0

<sup>z</sup>To convert (nmol CO<sub>2</sub> C kg<sup>-1</sup> C s<sup>-1</sup>) to (mg CO<sub>2</sub> C kg<sup>-1</sup> C h<sup>-1</sup>) multiply by 0.080406  
<sup>y</sup>To convert (pmol C<sub>2</sub>H<sub>4</sub> C kg<sup>-1</sup> C s<sup>-1</sup>) to (μl C<sub>2</sub>H<sub>4</sub> C kg<sup>-1</sup> C h<sup>-1</sup>) multiply by 0.08064

the 4 cultivars tested. Browning intensity of Bartlett and Bosc pear slices was much lower than that of Anjou and Red Anjou pears based on cut surface a\* values. Bartlett and Bosc pear slices experienced a large decrease in flesh firmness after slicing and storage at 10 °C, while Anjou and Red Anjou pear slices had only moderate declines in firmness of less than 2 N (12% to 14% of initial) after 6 d at 10 °C (Fig. 1C). In contrast, Bartlett pear slices experienced severe tissue softening (82% of initial) during the same period.

Among the 4 pear cultivars tested, respiration and C<sub>2</sub>H<sub>4</sub> production rates at 10 °C were consistently highest in whole and sliced Bartlett pears (Fig. 2). Whole and sliced Bosc pears were intermediate in their respiration and C<sub>2</sub>H<sub>4</sub> production rates, while whole and sliced Anjou and Red Anjou pears consistently had the low-

est respiration and C<sub>2</sub>H<sub>4</sub> production rates. There was no difference in the respiration rates between whole and sliced Bartlett pears, but Bosc, Anjou, and Red Anjou pear slices had 35%, 64%, and 232% greater respiration rates, respectively, than whole fruit of the same cultivar (Fig. 2). Among all cultivars tested, C<sub>2</sub>H<sub>4</sub> production on average was not significantly different in fruit slices than in whole fruit during 6 d at 10 °C.

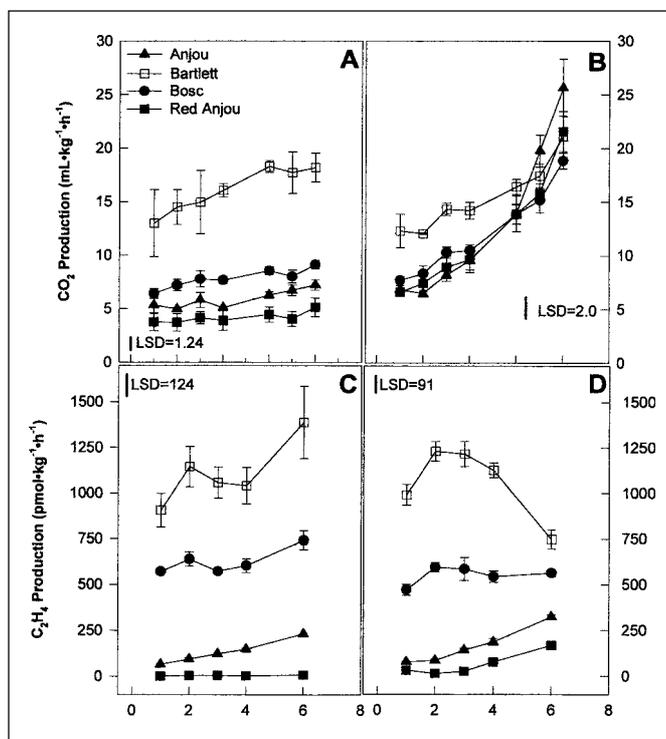
Bartlett pear slices had the highest rate of respiration, and there was no difference in respiration rates among the Anjou, Bosc, or Red Anjou slices at 0, 10, or 20 °C (Table 1). In all cultivars tested, CO<sub>2</sub> evolution increased between 2 and 4 fold when temperatures increased from 0 to 10 °C. This demonstrates that pear slices are very sensitive to temperature abuse, and even small increases in tem-

perature will dramatically increase their respiration rate.

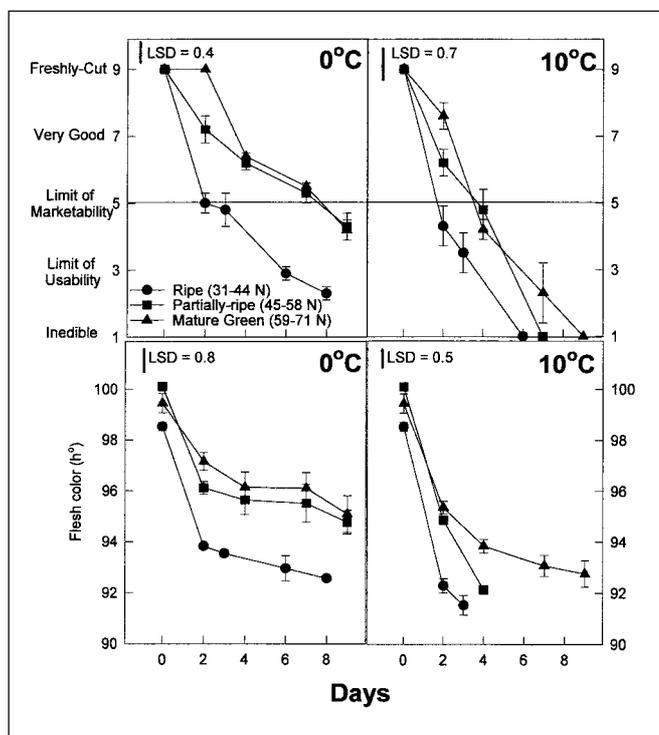
C<sub>2</sub>H<sub>4</sub> production rates were consistently highest in Bartlett pear slices and intermediate in Bosc pear slices (Table 1). At all temperatures tested, Anjou and Red Anjou pear slices consistently had very low C<sub>2</sub>H<sub>4</sub> production rates. C<sub>2</sub>H<sub>4</sub> production rates of individual cultivars correlated with the loss of flesh firmness, with high C<sub>2</sub>H<sub>4</sub> producing cultivars experiencing a faster rate of flesh softening.

**Ripeness stage**

Fruit ripeness stage at cutting had a significant effect on shelf life, with ripe pear slices having the shortest marketable shelf life of about 2 d at 0 °C (Fig. 3A). Partially ripe and mature-green slices had a shelf life based on visual quality of 8 d at 0 °C (Fig 3A). Shelf life at 10 °C was general-



**Fig. 2—Cultivar differences in the respiration and C<sub>2</sub>H<sub>4</sub> production rates of whole pears (A and C) and pear slices (B and D) that were held in air at 10 °C and 90% to 95% relative humidity. Data shown are the means (± standard deviation) of 3 replicates. Vertical bar = pooled LSD at the 5% level.**



**Fig. 3—Ripeness stage (based on N flesh firmness) effects on the shelf life of fresh-cut Bartlett pear slices based on visual quality evaluation using a 1 to 9 subjective (hedonic) scale and cut surface browning, as measured by flesh hue angle (h) during storage at 0 °C and 10 °C. Data shown are the means (± standard deviation) of 3 replicates. Vertical bar = pooled LSD at the 5% level.**

ly about half of that at 0 °C. Storage temperature and fruit ripeness stage at cutting both significantly affected the rate and intensity of enzymatic browning, as indicated by the flesh hue angle (h°) value (Fig. 3C and 3D). Slices made from ripe pears held at 0 °C and 10 °C exhibited the most intense enzymatic browning of all ripeness classes tested, and discoloration was most severe at 10 °C. Partially ripe and mature-green pear slices exhibited significantly less cut surface darkening at 0 °C than ripe fruit. The optimal pear fruit ripeness stage for fresh-cut processing based on flesh firmness is between 44 to 58 N. If softer fruit are used, a reduction in shelf life occurs due to increased cut surface browning. If mature-green fruit are used, eating quality may be compromised due to lack of juiciness and fruity aroma.

Pear slices irrespective of fruit ripeness stage at cutting, exhibited loss of sheen and gloss at the cut surface as well as development of an abrasive surface texture. The cut surface loss of sheen or gloss has also been reported to occur on fresh-cut peeled carrots (Cisneros-Zevallos and

others 1995). We propose that localized dehydration of ruptured cells at the cut surface is the cause of this problem in pear slices just as in minimally processed carrots, since the total loss in mass by the slices was less than 0.2% after storage at 0 °C for 9 d. Microscopic examination of the cut surface revealed protruding stone cells that are the probable cause of the development of an abrasive surface.

#### Fruit size

Fruit size (122, 135, or 152 g) did not have a significant effect on fresh-cut pear slice shelf life, based on visual quality and firmness (Fig. 4A and 4C). However, pear slices derived from smaller fruit (122 or 135 g) discolored at their cut surface more rapidly than slices derived from larger (152 g) fruit (Fig. 4B). Smaller fruit (122 and 135) also had lower soluble solids content (data not shown) than larger fruit, and this may effect overall eating quality for consumers. Smaller whole fruit, which often receive lower prices in the marketplace, may be effectively used for value-added fresh-cut fruit slices if cut surface browning can be prevented.

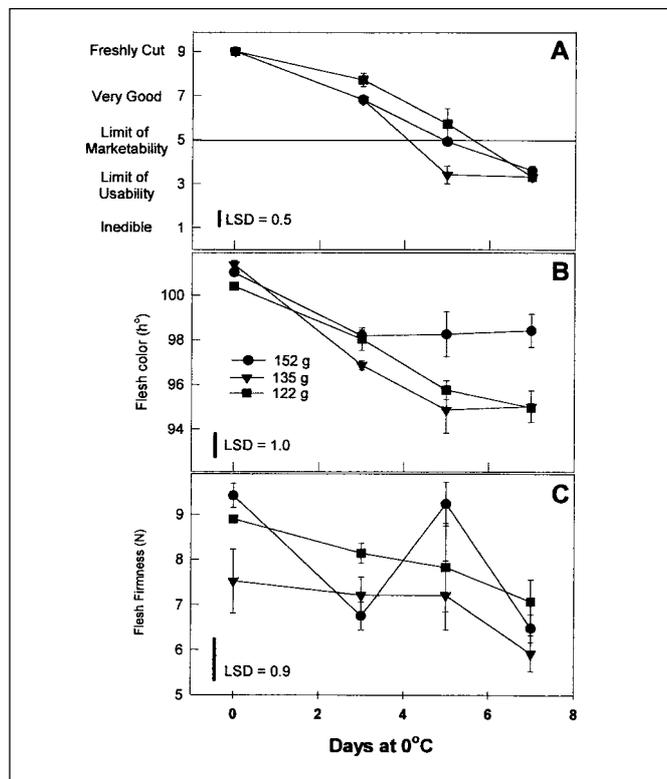
#### Storage conditions and growing region

Compared to air storage, controlled atmosphere (2% O<sub>2</sub> + 98% N<sub>2</sub>) storage at -1 °C of whole mature-green pears extended the shelf life of subsequent slices by 1 to 2 d (Fig. 5). Irrespective of growing region, there was significant reduction in the shelf life of slices with increased storage duration of intact pears at -1 °C in air or in a controlled atmosphere (2% O<sub>2</sub> + 98% N<sub>2</sub>).

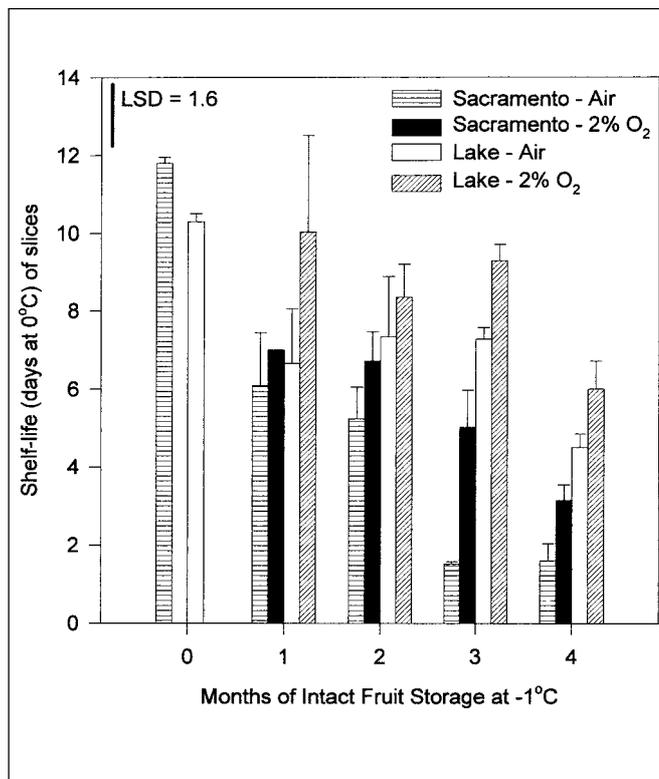
#### Conclusions

PEAR CULTIVARS VARY GREATLY IN THE shelf life of their fresh-cut slices based on flesh softening and surface discoloration. Bartlett pears are the best suited cultivar for fresh-cut processing because they exhibited the longest post-cutting shelf life among the 4 cultivars tested. Ripeness stage, fruit size, and storage time after harvest are all important factors that effect the post-cutting life of pear slices and must be carefully controlled if commercial production is attempted. Investigation of the efficacy of physical and chemical treatments to extend the shelf life of fresh-cut pears is warranted.

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**Fig. 4**—Effects of whole Bartlett pear fruit size on pear slice visual quality (A), flesh hue angle (B), and firmness (C). Whole fruit were ripened at 20 °C to 45 to 58 N firmness range, cut, and then kept in air at 0 °C and 90% to 95% relative humidity. Data shown are the means of 3 replicates. Vertical bar = pooled LSD at the 5% level.



**Fig. 5**—Effects of growing region (Sacramento or Lake counties) as well as storage time and atmosphere (air or 2% O<sub>2</sub> + 98% N<sub>2</sub>) on the shelf life of fresh-cut pear slices based on the number of days to deteriorate to a quality score of 5 (limit of marketability). After storage at -1 °C, whole fruit were ripened at 20 °C to 45 to 58 N firmness range, cut, and then kept in air at 0 °C and 90% to 95% relative humidity. Data shown are the means of 3 replicates. Vertical bar = pooled LSD at the 5% level.

## Materials and Methods

### Cultivars and production areas

Bartlett pears (110 count, mean fruit mass = 166 g, produce of Argentina), Bosc pears (110 count, mean fruit mass = 162 g, produce of Chile), Anjou pears (100 count, mean fruit mass = 210 g, produce of Washington), and Red Anjou (55 count, mean fruit mass = 182 g, produce of Oregon) were obtained from a commercial wholesale produce distributor in Sacramento, Calif. Pears were ripened and cooled as outlined below, and the firmness of each individual fruit was determined to select Anjou, Bartlett, and Bosc pear fruit that had a flesh firmness within the range of 27 to 45 N. Red Anjou whole fruit at cutting had a mean firmness of  $65 \pm 8.9$  N. Fruit slices were then processed as outlined below and stored at 0, 10, and 20 °C in air. Whole fruit that had also been partially ripened were held at 10 °C.

### Ripeness stage

Bartlett pears (110 count, mean fruit mass = 166g) were obtained on the day of harvest from commercial grower/shippers in Lake and Sacramento counties, transported to Davis, Calif., and stored at -1 °C in air until they were used in various studies. Fruit were partially ripened and then segregated into the following 3 categories: ripe (31 to 44 N), partially ripe (45 to 58 N), and mature-green (59 to 71 N), based on flesh firmness as outlined below. Fruit slices were then prepared as outlined below and stored at 0 °C in air.

### Fruit size

Bartlett pears (mean mass = 122, 135, and 152 g) were obtained on the day of harvest from a commercial grower/shipper in Sacramento County, Calif., transported to Davis, Calif., and stored at -1 °C in air until they were used in our studies. Whole pear fruit were partially ripened and cooled as outlined below, and the firmness of each individual fruit

was determined to select pears that had a flesh firmness of 45 to 58 N. Fruit slices were then prepared as outlined below and stored at 0 °C in air.

### Storage regime and growing region

Bartlett pears (110 count, mean fruit mass = 166g) were obtained on the day of harvest from commercial grower/shippers in Lake or Sacramento counties, transported to Davis, Calif., and stored at -1 °C in air or in 2% O<sub>2</sub> (balance N<sub>2</sub>) until they were used to prepare slices as outlined below and stored at 0 °C in air.

### Ripening conditions

Fruit were ripened at 20 °C and 90% to 95% relative humidity in air + 10 Pa (100 Fl C L<sup>-1</sup>) C<sub>2</sub>H<sub>4</sub>. Ripeness stage was based on measuring the force required for an 8 mm probe to penetrate the cheek of 20 pears per lot, with the skin removed, to a depth of 10 mm using a University of California firmness tester (Western Industrial Supply Co., San Francisco, Calif., U.S.A.). After ripening, fruit were cooled to approximately 0 °C in 3 to 4 h using a laboratory-scale forced-air cooling unit and held overnight at 0 °C until cut.

### Fruit cutting and storage

Before cutting, the firmness of each fruit was determined to assure that fruit was of the appropriate ripeness stage for each experiment. These pears were each cut into 8 slices (wedges) with a sharp stainless steel knife, and the wedge used to determine firmness was discarded. Fruit wedges were then dipped in 4 °C-distilled water with 2.7 FM sodium hypochlorite for 2 min, gently dried by hand with cheesecloth, and then placed (20 slices per replicate) into 2-L jars ventilated with a continuous flow (100 mL min<sup>-1</sup>) of humidified air at 0, 10, or 20 °C. All data points are means of 3 replicates. In cultivar experiments, 3 partially ripe fruit per replicate and 3 repli-

cates were held at 10 °C in a continuous flow (100 mL min<sup>-1</sup>) of humidified air.

### Quality evaluations

The visual quality in each replicate was determined based on the following visual hedonic scale: 9 = excellent, just sliced; 7 = very good; 5 = good, limit of marketability; 3 = fair, limit of usability; and 1 = poor, inedible. A color photograph of slices rated via this scale was used by 2 or 3 judges to score slices based on color, visible structural integrity, and general visual appeal. A weighted average of individual fruit slice quality scores was used to determine the mean visual quality score for each replicate. CIE L\*a\*b\* values were determined with a Minolta chromameter (Model CR-200, Minolta, Ramsey, N.J., U.S.A.) calibrated to a white porcelain reference plate (L\* = 97.95, a\* = -0.39, b\* = 2.00). The a\* color value or hue angle (h) was used as an indicator of cut surface browning intensity (Sapers and Douglas 1987). Pear slice firmness (penetration force) was determined by measuring the force required for a 3 mm probe to penetrate the slice surface (midpoint between endocarp and skin), held perpendicular to the probe, to a depth of 10 mm using a University of California firmness tester.

### Respiration and ethylene production rates

The CO<sub>2</sub> and C<sub>2</sub>H<sub>4</sub> production rates were determined by an infrared gas analyzer (Horiba-Pir 2000 R; Horiba Instruments Co., Irvine, Calif., U.S.A.) and a gas chromatograph (Carle model 211, Carle Instruments Co., Anaheim, Calif., U.S.A.) equipped with a flame ionization detector, respectively.

### Statistical analysis

Data were treated for multiple comparisons by analysis of variance with least significant difference (LSD) between means determined at 5% level (Geng 1997).

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