

# Physiological and Quality Responses of 'Bartlett' Pears to Reduced O<sub>2</sub> and Enhanced CO<sub>2</sub> Levels and Storage Temperature

Dangyang Ke, Hendrik van Gorsel, and Adel A. Kader<sup>1</sup>

Department of Pomology, University of California, Davis, CA 95616

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**Abstract.** 'Bartlett' pears (*Pyrus communis* L.) tolerated up to 10 days of exposure to atmospheres containing 1.0%, 0.5%, or 0.25% O<sub>2</sub> at 0, 5, or 10C without any detrimental effects on their quality attributes. The fruits also tolerated 4 to 6 days of exposure to air enriched with 20%, 50%, or 80% CO<sub>2</sub> at the three temperatures. The beneficial effects of exposures to the O<sub>2</sub>-reduced or CO<sub>2</sub>-enriched atmospheres included reduction of respiration and ethylene production rates and retardation of skin yellowing and flesh softening. While 1.0% or 0.5% O<sub>2</sub> and 20% CO<sub>2</sub> did not increase ethanol and acetaldehyde contents, 0.25% O<sub>2</sub> slightly increased and 50% or 80% CO<sub>2</sub> dramatically increased the contents of these two volatiles in juice of the fruits. The effects of low O<sub>2</sub> or high CO<sub>2</sub> on the above attributes generally became more pronounced at the higher temperatures. The low O<sub>2</sub> or high CO<sub>2</sub> treatments did not significantly affect either soluble solids content or titratable acidity. Low O<sub>2</sub> did not influence, but high CO<sub>2</sub> slightly increased pH of the fruits.

There have been many studies of controlled-atmosphere (CA) storage of fresh fruits and vegetables, but these have largely evaluated the responses of the commodities to moderately low O<sub>2</sub> (2% to 3%) and/or high CO<sub>2</sub> ( $\leq 5\%$ ) levels over long-term storage. In recent years, there has been increased interest in studying the responses of fruits and vegetables to short-term exposure to O<sub>2</sub> levels  $\leq 1\%$  and CO<sub>2</sub> levels  $\geq 20\%$ . Such atmospheres may be effective as a quarantine treatment for insect control in fresh fruits and vegetables (Aharoni et al., 1979; Lidster et al., 1981, 1984; Soderstrom and Brandl, 1987; Soderstrom et al., 1986).

Exposure of 'Granny Smith' apples to O<sub>2</sub> levels  $\leq 0.5\%$  for 9 days has been reported to have beneficial effects in scald control and in delay of fruit softening and loss of greenness (Little et al., 1982). Nichols and Patterson (1987) showed that short-term storage of 'Delicious' apples to 0.5% or 0.75% O<sub>2</sub> maintained fruit firmness and increased ethanol content. Yoshida et al. (1986) reported that storage of 'Bartlett' pears in 1% O<sub>2</sub> for 4 months reduced ethylene production rate and retained higher levels of organic acids. Claypool (1969, 1973) showed that low-O<sub>2</sub> atmospheres (0.5% to 1%) prolonged storage life and caused no injury to 'Bartlett' pears. Long-term storage of 'd'Anjou' pears in 1.0% O<sub>2</sub> maintained higher dessert quality and higher contents of amino acids and organic acids than storage in air, and prevented scald disorder and internal brown core (Chen and Mellenthin, 1982, Chen et al., 1981; Mellenthin et al., 1980).

Couey and Wright (1977) reported that short-term exposure of 'd'Anjou' pears to 12% CO<sub>2</sub> for 14 days before storage reduced stem decay and scuffing, improved flavor retention, and retarded softening after either regular or CA storage. Similarly, prestorage high CO<sub>2</sub> (10% to 20%) treatments for 10 to 15 days retained higher firmness, acidity, and flavor scores of 'Golden Delicious' apples (Couey and Olsen, 1977) and retarded soft-

ening of 'McIntosh' apples (Bramlage, 1977). Recently, Kerbel et al. (1988) showed that 10% CO<sub>2</sub> reduced rates of respiration and ethylene production, contents of protein and fructose-1,6-bisphosphate, and activities of ATP:phosphofructokinase and PPI:phosphofructokinase. However, the high CO<sub>2</sub> treatment increased fructose-6-phosphate and fructose-2,6-bisphosphate levels. Frenkel and Patterson (1977) reported that elevated CO<sub>2</sub> (5% to 20%) decreased succinic dehydrogenase activity and caused disintegration of plastids, vacuoles, and cytoplasmic matrix in 'Bartlett' pears. Chen et al. (1985) reported that elevated CO<sub>2</sub> levels (up to 3%) reduced ethylene production rates and retained higher contents of organic acids in 'Bartlett' and 'Bose' pears. However, one of the major problems with the storage of pear fruits in elevated CO<sub>2</sub> atmospheres is the possible development of CO<sub>2</sub> injury (Blanpied, 1975; Hansen, 1957; Hansen and Mellenthin, 1962; Lau et al., 1977; Little and Pegg, 1987; Porritt and Meheriuk, 1977, 1982; Smock, 1979), which largely limits the use of these treatments in long-term storage of the fruits.

We report here on the effects of short-term exposures to O<sub>2</sub> levels  $\leq 1\%$  or CO<sub>2</sub> levels  $\geq 20\%$  on postharvest physiology and quality attributes of 'Bartlett' pears as affected by temperature. This study was aimed at determining the tolerance of the fruits to very low O<sub>2</sub> or very high CO<sub>2</sub> stresses and the potential of using these treatments for postharvest insect control. CA treatments can be used for quarantine procedures only when they can effectively kill the insect of interest without detrimental effects on the quality attributes of the fruits.

## Materials and Methods

**Materials.** For the determinations of quality attributes and volatile contents, mature-green fruits of 'Bartlett' pear were obtained from commercial packinghouses in Sacramento and Lake Counties, Calif., within 24 hr of harvest. Defective fruits were sorted out and the good fruits were matched by color. Ten selected fruits were put in a 4-liter glass jar as one replicate, with three replicates used per treatment. For the measurements of respiration and ethylene production rates, the fruits were stored at -1C until the beginning of the experiment, and there were four replicates consisting of eight fruits each in these measurements. The jars were then placed in a 0, 5, or 10C room and ventilated with humidified air or other gas mixtures at a contin-

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<sup>1</sup>To whom reprint requests should be addressed.

uous flow of 70, 140, or 280 ml·min<sup>-1</sup>, respectively. Flow boards and capillary tubing were used for flow control.

**Treatments.** For one set of experiments, fruit samples were kept in air and in 1.0%, 0.5%, 0.25%, or 0.03% O<sub>2</sub> (balance was N); for another set of experiments, fruits were kept in air and in 20%, 50%, or 80% CO<sub>2</sub> (balance was air). The fruit samples were kept in the above atmospheres for 4, 6, 8, or 10 days at 0, 5, or 10C before evaluation (of one half of the fruits in each jar) and transfer to air at 20C for 1 to 6 days to permit fruit ripening before final examination (of the other one half of the fruits in each jar).

**Gas analysis.** The required O<sub>2</sub> or CO<sub>2</sub> concentrations of all gas mixtures were verified each day by taking a 10-ml gas sample and analyzing it using a Carle gas chromatograph (Model 111; Carle Instruments, Anaheim, Calif.) with a thermal conductivity detector. For measurement of respiration, CO<sub>2</sub> production rates of fruits kept under O<sub>2</sub>-reduced atmospheres or air were measured each day by using a Horiba infrared CO<sub>2</sub> gas analyzer (Model SX-2; PIR-2000R; Horiba Instruments, Irvine, Calif.). Ethylene production rates were measured by detecting the ethylene concentration of the gas sample from each jar using a Carle gas chromatograph (Model 211) with a flame ionization detector.

**Evaluation of quality attributes.** Three initial samples of five fruits each were evaluated for skin color, flesh firmness, soluble solids content (SSC), pH, titratable acidity, and ethanol and acetaldehyde contents. Similar evaluations were also done after various durations of storage and after ripening at 20C. Skin color was measured with a Gardner XL-23 Tristimulus Colorimeter (Gardner Laboratory, Bethesda, Md.) using the "a" value in which a more-negative value indicates more greenness. Flesh firmness was measured as penetration force with a U.C. fruit firmness tester (Western Industrial Supply Co., San Francisco) using an 8-mm plunger tip. Fruit juice was made with a hand-press juice maker. Soluble solids content of the juice was measured by an Abbe refractometer, and pH and titratable acidity were determined by an automatic titrator with a PHM85 Precision pH meter (Radiometer, Copenhagen, Denmark), an ABU80 autoburette (Radiometer); a PRS12 Alpha printer (Radiometer), and a SAC80 sample changer (Radiometer). Ethanol and acetaldehyde contents were measured using a Hewlett Packard 5890A gas chromatograph with a flame ionization detector (at 250C) and a glass column (2 mm × 1.8 m) containing 5% Carbowax on 60/80 Carbowax as stationary phase (at 85C).

**Estimation of CO<sub>2</sub> injury.** The severity of CO<sub>2</sub>-induced injury was estimated using a subjective scale from 1 to 5 according to the area of flesh browning: 1 = 0% browning, 2 = 1% to 25% browning, 3 = 26% to 50% browning, 4 = 51% to 75% browning, and 5 = 76% to 100% browning.

## Results and Discussion

**Effects of short-term exposures to O<sub>2</sub>-reduced atmospheres.** Exposure of 'Bartlett' pears to 0.5% or 0.25% O<sub>2</sub> at 0C significantly reduced respiration rates, compared to those of air control (Fig. 1). However, CO<sub>2</sub> production rates increased when O<sub>2</sub> level was further reduced to 0.03%; this increase was probably due to the occurrence of anaerobic respiration (Boersig et al., 1988). After the fruits were transferred to air at 20C, respiration rates dramatically increased in the fruits of all treatments. But in the first 3 days after the transfer, respiration rates of the fruits previously exposed to low O<sub>2</sub> were still lower than those of the fruits continuously exposed to air, indicating some residual effects of the low-O<sub>2</sub> treatments.

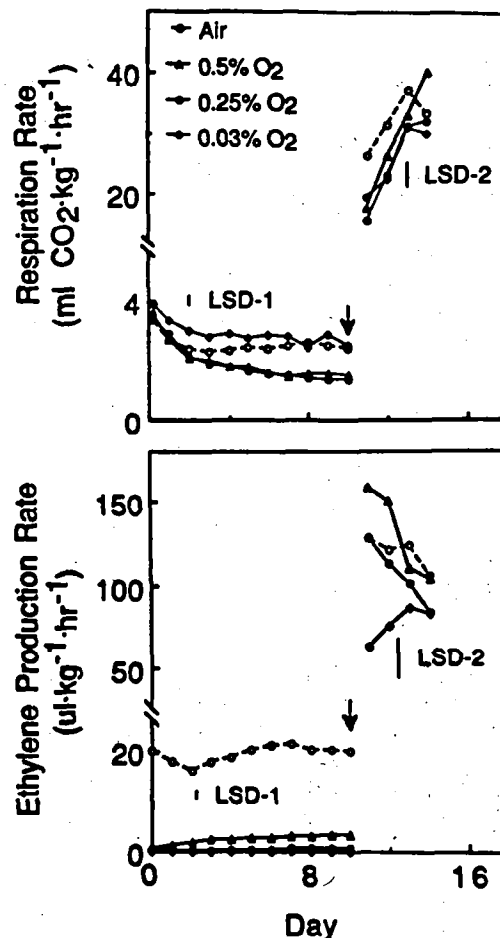


Fig. 1. Effects of low O<sub>2</sub> on respiration and ethylene production rates of 'Bartlett' pears kept at 0C for 10 days before transfer (indicated by arrow) to air to 20C for ripening.

Exposure to 0.5%, 0.25%, or 0.03% O<sub>2</sub> dramatically reduced ethylene production rates of the fruits (Fig. 1); the lower the O<sub>2</sub> concentration, the lower the ethylene production rate. Oxygen is required for the conversion of 1-aminocyclopropane-1-carboxylic acid to ethylene (Yang, 1985). After the fruits were transferred to air at 20C, ethylene production rates greatly increased in all treatments, but the rates of the fruits previously exposed to 0.03% O<sub>2</sub> were still lower than those of the other treatments. The reduction in respiration and ethylene production rates by low O<sub>2</sub> levels can be beneficial for extending the storage life of the fruits.

'Bartlett' pears tolerated 1.0%, 0.5%, or 0.25% O<sub>2</sub> at 0, 5, or 10C for up to 10 days without any detrimental effects on their quality attributes. The fruits also tolerated 0.03% O<sub>2</sub> at 0C for 10 days without any injury. The low-O<sub>2</sub> treatments did not significantly affect SSC, pH, and titratable acidity of the fruits (data not shown). The beneficial effect of keeping these fruits in the O<sub>2</sub>-reduced atmospheres at 10C was the retardation of ripening, as indicated by delayed skin yellowing and flesh softening (Table 1) when compared to fruits continuously exposed to air. These effects were less pronounced or absent when the fruits were kept at 0 or 5C, and there were no appreciable differences among pears from the three low-O<sub>2</sub> treatments.

'Bartlett' pears kept in 1.0% or 0.5% O<sub>2</sub> had almost the same levels of ethanol content as the fruits continuously kept in air (Fig. 2), but the pears kept in 0.25% O<sub>2</sub> had a higher ethanol content. The effect of 0.25% O<sub>2</sub> was greater the higher the

Table 1. Effects of temperature and O<sub>2</sub> concentration on speed of degreening of the skin and softening of the flesh of 'Bartlett' pears kept at 0, 5, or 10C for 10 days before transfer to air at 20C for ripening.

Treatment during first 10 days		Mean no. of days to reach	
Temp (°C)	% O <sub>2</sub>	CDM <sup>2</sup> "a" value of -8	Firmness of 60 N
0	Air	13	12
	1.0	14	12
	0.5	14	12
	0.25	14	12
5	Air	13	12
	1.0	14	12
	0.5	14	12
	0.25	14	12
10	Air	11	9
	1.0	13	12
	0.5	13	12
	0.25	14	12

<sup>2</sup>CDM = color difference meter.

temperature. After the fruits were transferred from 0.25% O<sub>2</sub> at 10C to air at 20C for ripening, ethanol content dropped to only 37% of the previous value. Similarly, exposure to 0.25% O<sub>2</sub> slightly increased acetaldehyde content. However, these slight increases in ethanol and acetaldehyde contents by the low-O<sub>2</sub> treatments did not affect the flavor of 'Bartlett' pears. The fruits previously exposed to the low-O<sub>2</sub> atmospheres tasted as good, as judged in informal evaluations, as the fruits kept continuously in air when both were later ripened in air at 20C. While a large increase in acetaldehyde and ethanol contents could result in off-flavors, a small amount of these volatiles is essential for the development of characteristic flavor of many products (Lees and Jago, 1978), and the applications of these compounds at low

concentrations may enhance fruits' sensory quality (Paz et al., 1981).

*Effects of short-term exposures to CO<sub>2</sub>-enriched atmospheres.* 'Bartlett' pears exposed to 20%, 50%, or 80% CO<sub>2</sub> (balance was air) at 5 or 10C showed delayed skin yellowing and flesh softening (Table 2). The higher the CO<sub>2</sub> concentration during holding at 5 or 10C, the longer it took for the fruits to ripen.

'Bartlett' pears previously kept in 20%, 50%, or 80% CO<sub>2</sub> had a slightly higher pH at the time of transfer to air at 20C for evaluation. For example, after 10 days at 0C, pH values were 3.98, 4.07, 4.09, and 4.20 in pears previously kept in air, 20%, 50%, and 80% CO<sub>2</sub>, respectively. These treatments did not significantly affect either SSC (12.1% to 12.6%) or titratable acidity (0.18% to 0.24%) of the fruits.

While 20% CO<sub>2</sub> did not significantly influence ethanol and acetaldehyde contents, as compared with the air control, 50% or 80% CO<sub>2</sub> greatly increased the contents of these two volatiles in 'Bartlett' pears (Fig. 3). The effects of 80% CO<sub>2</sub> were greater than those of 50% CO<sub>2</sub>, and the effects at 10C were the greatest. Ethanol content was 10 to 20 times higher than the corresponding acetaldehyde content. When the fruits were kept in 80% CO<sub>2</sub> for only 4 days, ethanol content dropped to ≈ 30% of the previous value during the subsequent 4 days of fruit ripening in air at 20C (410 to 440 μl-liter<sup>-1</sup> at transfer and 70 to 150 μl-liter<sup>-1</sup> at ripening). However, when the fruits were kept in 50% or 80% CO<sub>2</sub> for 10 days, ethanol content remained quite high, even after the fruits were transferred to air at 20C for ripening (Fig. 3). The persistently high ethanol and acetaldehyde contents in the juice of 'Bartlett' pears that were kept in 50% or 80% CO<sub>2</sub> for 10 days might have resulted in off-flavor development.

The tolerance of 'Bartlett' pears to high CO<sub>2</sub> levels depended on both temperature and CO<sub>2</sub> concentration. At 0 or 5C, CO<sub>2</sub> injury was observed after 6 days of exposure to 20%, 50%, or

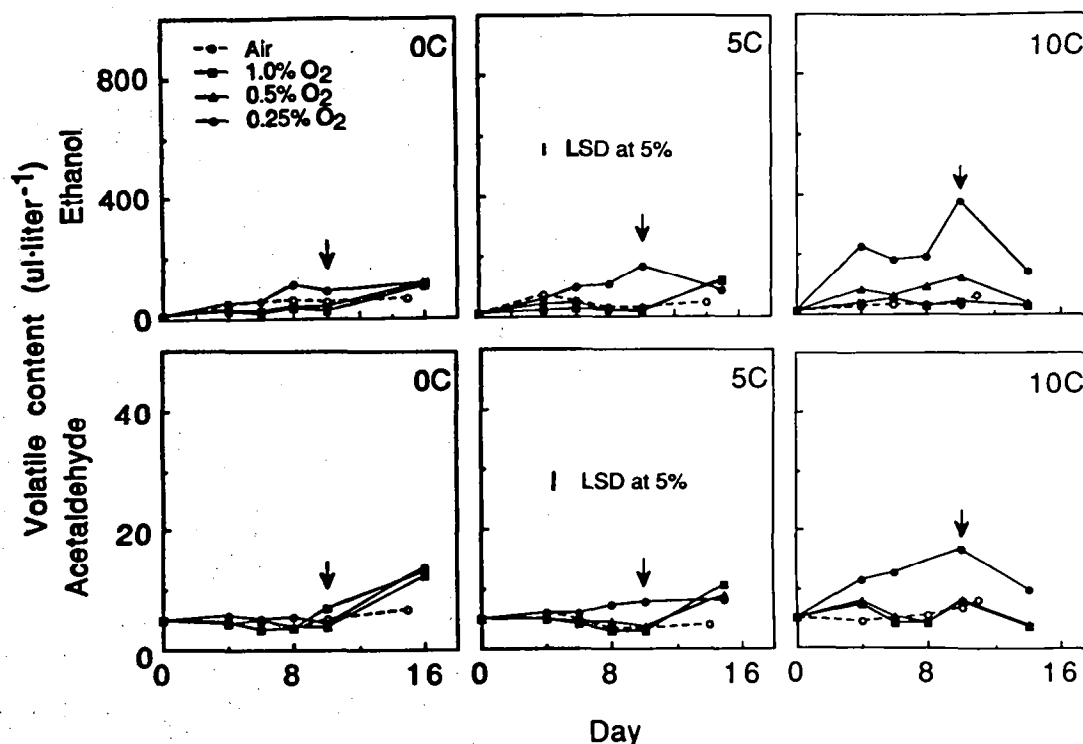


Fig. 2. Effects of reduced concentrations of O<sub>2</sub> on ethanol and acetaldehyde contents in juice of 'Bartlett' pears kept at 0, 5, or 10C for 10 days before transfer (indicated by arrow) to air at 20C for ripening.

Table 2. Effects of temperature and CO<sub>2</sub> concentration on speed of degreening of the skin and softening of the flesh and on severity of CO<sub>2</sub> injury (flesh browning) of 'Bartlett' pears kept at 0, 5, or 10C for 10 days before transfer to air at 20C for ripening.

Treatment during first 10 days		Mean no. of days to reach		Days to see CO <sub>2</sub> injury	Injury score <sup>y</sup> after 10 days of storage
Temp (°C)	% CO <sub>2</sub>	CDM <sup>z</sup> value of -8	Firmness of 60 N		
0	Air	12	11	NIO <sup>x</sup>	NIO
	20	12	12	6	1.1 b <sup>w</sup>
	50	12	12	6	1.3 b
	80	12	12	6	1.5 b
5	Air	10	10	NIO	NIO
	20	12	12	6	1.2 b
	50	12	12	6	1.5 b
	80	13	12	6	1.3 b
10	Air	5	5	NIO	NIO
	20	11	11	6	1.6 b
	50	12	12	4	3.1 a
	80	14	14	4	1.7 b

<sup>z</sup>CDM = color difference meter.

<sup>y</sup>Based on the area of brown flesh tissue: 1 = 0% browning, 2 = 1% to 25% browning, 3 = 26% to 50% browning, 4 = 51% to 75% browning, 5 = 76% to 100% browning.

<sup>x</sup>NIO = no injury observed during the experimental period.

<sup>w</sup>Mean separation among all temperature-CO<sub>2</sub> concentration combinations by LSD at *P* = 0.05.

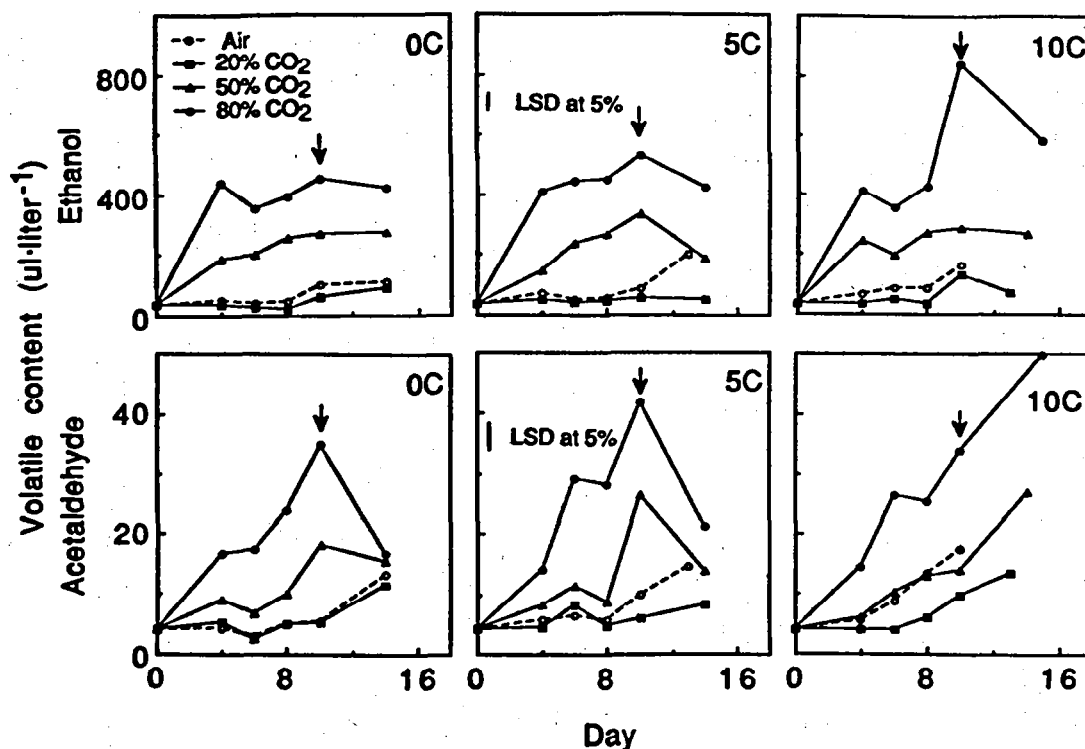


Fig. 3. Effects of elevated CO<sub>2</sub> levels on ethanol and acetaldehyde contents in juice of 'Bartlett' pears kept at 0, 5, or 10C for 10 days before transfer (indicated by arrow) to air at 20C for ripening.

80% CO<sub>2</sub> (Table 2). At 10C, CO<sub>2</sub> injury occurred after 6 days of exposure to 20% CO<sub>2</sub>, while injury already was observed after only 4 days of treatment with 50% or 80% CO<sub>2</sub>. Carbon dioxide injury started in the center of the fruits with a dark brown discoloration. The dark area increased as the injury became more severe. In extreme cases of injury, the whole flesh tissue became dark brown and soft and the skin of the fruit also

became brown. These CO<sub>2</sub> injury symptoms were similar to those described by several other researchers in pears (Blanpied, 1975; Claypool, 1973; Hansen, 1957; Hansen and Mellenthin, 1962). There was a large variation in severity of CO<sub>2</sub> injury among fruits in each treatment. After 10 days of exposure, 50% CO<sub>2</sub> at 10C resulted in the highest injury score, whereas no significant differences in CO<sub>2</sub> injury scores were observed among

all the other CO<sub>2</sub> concentration/temperature combinations. The fact that 50% CO<sub>2</sub> resulted in a higher injury score (tissue browning) than 80% CO<sub>2</sub> at 10C may be due to the lower O<sub>2</sub> level in the latter treatment (≈ 4% O<sub>2</sub> vs. 10% O<sub>2</sub>). Ong (1987) showed that 1.5% O<sub>2</sub> + 20% CO<sub>2</sub> resulted in a lower browning score than 20% CO<sub>2</sub> alone in 'Bartlett' pears. Similarly, Ke and Saltveit (1989) found that 1.5% O<sub>2</sub> could inhibit phenolic metabolism and tissue browning induced by 11% CO<sub>2</sub> in crisphead lettuce tissue.

Based on the data presented above, the following treatment combinations can be used on 'Bartlett' pears without detrimental effects on their quality attributes: up to 10 days exposure to 1.0%, 0.5%, or 0.25% O<sub>2</sub> at 0, 5, or 10C; up to 6 days exposure to 20%, 50%, or 80% CO<sub>2</sub> at 0 or 5C; 6 days in 20% CO<sub>2</sub> at 10C; or 4 days in 50% or 80% CO<sub>2</sub> at 10C. Once entomologists have determined which of these combinations can control specific insects, such treatments may be approved by quarantine authorities for commercial use. Accurate and sensitive monitoring techniques for O<sub>2</sub> and CO<sub>2</sub> concentrations and for temperature will be required to verify any approved treatment conditions to help protect the fruits against exposure to conditions that result in low O<sub>2</sub> and/or high CO<sub>2</sub> injuries.

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