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Effect of ethylene in the storage environment on quality of ‘Bartlett pears’

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Abstract

The effect of ethylene on the quality of ‘Bartlett pears’ stored at either -1 or 2 °C was examined. Fruit from three different harvest dates were stored for 3 months in 0, 1, 5 or $10 \mu\text{l l}^{-1}$ ethylene. Quality attributes, including skin color, firmness, scald and internal browning, were assessed when the fruit were removed from storage and after 4 days ripening at 20 °C. All levels of ethylene increased the incidence of physiological disorders. However, the effect of ethylene was minor compared with the influence of temperature. Fruit stored at -1 °C remained firm and green, subsequently ripening normally at 20 °C, irrespective of exposure to ethylene. In contrast, all of the pears kept at 2 °C softened and yellowed during storage, and developed symptoms of superficial scald and internal browning. The severity of these disorders increased when fruit were ripened at 20 °C. It was concluded that although it is desirable to minimize ethylene in the storage atmosphere, benefits are likely to be minor compared with the potential gains from good temperature management.

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1. Introduction

The presence of ethylene in the storage atmosphere has been shown to decrease the storage life of a number of fruit and vegetables, as well as increasing decay and the incidence of a number of physiological disorders. In the case of climacteric fruit, exogenous ethylene accelerates ripening,

which is usually undesirable in stored fruit. Wills and Warton (2000) have suggested that the concentration of ethylene in the storage environment can be directly related to the rate of quality loss in a wide range of fruit and vegetables.

Exposure to ethylene has been shown to increase softening of some fruits even during cold storage. However, results are somewhat mixed. For example, ethylene is a major factor determining storage life of kiwifruit, which soften significantly during storage at 0 °C in response to ethylene concentrations as low as 10 nl l^{-1} (McDonald and Harman, 1982; Ben-Arie and Sonego, 1985; Retamales and Campos, 1997). Some cultivars of persimmon

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fruit, such as ‘Triumph’, are sensitive to ethylene even when stored under low oxygen levels at < 0 °C (Ben-Arie et al., 1989), while others, such as ‘Fuyu’, appear to be relatively insensitive under similar conditions (Brackmann et al., 1999). Apples are similar, in that the effect of ethylene varies between cultivars (DeEll et al., 2001). Removal of ethylene from controlled atmosphere chambers has been shown to reduce softening of varieties such as ‘Bramleys Seedling’, ‘Golden Delicious’ and ‘McIntosh’ (Knee and Hatfield, 1981; Granger and Rousselle, 1985). The same strategy had mixed, slight, or no effect on ‘Cox’s Orange Pippin’, ‘Cortland’ and ‘Spartan apples’, respectively (Stow et al., 2000; Lange, 1986; Fica, 1991).

There is little information on the effect of ethylene on stored pears. European pears build up significant levels of internal ethylene during storage at -1 °C (Blankenship and Richardson, 1985; Gerasopoulos and Richardson, 1997), with ‘Conference pears’ producing up to $35 \mu\text{mol kg}^{-1} \text{h}^{-1}$ of ethylene during storage at this temperature (Knee, 1987). High levels of ethylene are associated with an increase in ‘brown heart’ in pear fruit stored in low oxygen atmospheres (Scott and Wills, 1973). Despite this effect, Retamales et al. (1998) found little benefit in removing ethylene from the environment around ‘Packhams Triumph’ and ‘Beurre Bosc’ pears held at -0.5 °C.

Although the effects of ethylene on cool-stored ‘Bartlett pears’ are unclear, the fruit are certainly very sensitive to exogenous ethylene at room temperature. Ethylene treatments can be used to ripen pears, avoiding or decreasing the chilling requirements of pear varieties such as ‘Bon Chretien’, ‘d’Anjou’, ‘Bartlett’ and ‘Forelle’ (Maxie and Ginsburg, 1974; Chen et al., 1997; Agar et al., 1999; DuToit et al., 2001). While the effects of ethylene are likely to be greatly reduced at low temperatures, it would seem possible that high concentrations may increase softening and yellow color development during storage. In this case, removing ethylene could extend storage life and improve quality.

Both the amount of ethylene that fruit produce and the effects of ethylene are influenced by temperature and fruit maturity (Agar et al., 1999). It is important to understand the extent to

which ethylene reduces pear quality during cold storage as its removal can be costly. As with other storage practices, the cost of any procedure must be less than the resulting economic benefits. It is, therefore, critical to know the effects of different ethylene concentrations on fruit quality and storage life.

In this study, we have investigated the effect of various ethylene concentrations in the storage environment on the quality of ‘Bartlett pears’. The interaction of storage temperature and fruit maturity at harvest on the effects of ethylene was also tested. The results are discussed in terms of the economic value of removing ethylene from rooms containing stored pears.

2. Materials and methods

2.1. Fruit material

Mature green ‘Bartlett pears’ (*Pyrus communis* L.) were harvested from commercial orchards in Sacramento (7/12/2001—harvest 1) and Mendocino (8/2/2001—harvest 2; 8/14/2001—harvest 3) County. On each occasion, fruit were selected from three harvest bins, giving three replicate groups of fruit. Pears were transported to the University of California, Davis in an air-conditioned vehicle and sorted to obtain undamaged fruit of uniform size and color. The pears were then numbered and packed into standard pear cartons in groups of 60 (20×3 replicates). Each carton was placed inside a metal tank with a lid constructed so as to fit into a water-filled trough, ensuring a hermetic seal. The tanks were stored at either -1 or 2 °C for the duration of the experiment.

2.2. Gas treatments

The storage tanks were flushed continuously with humidified air containing 0, 1, 5 or $10 \mu\text{l l}^{-1}$ ethylene. Concentrations of CO_2 and ethylene in the air exhausting from each tank were determined by rapid gas analysis (VIA510, Horiba, Japan) or gas chromatography (Model AGC Series 400, Hach-Carle Co., USA) in order to verify that the gas composition was close to the set values.

As storage progressed, some of the fruit began to produce measurable ethylene, increasing the concentrations inside the tanks. To maintain the gas at the desired levels, the ethylene concentration in the air-stream entering the tanks was reduced or eliminated, and the rate of airflow through each tank was increased as necessary. In the case of the fruit stored at 2 °C, it became necessary to also add mesh containers filled with potassium permanganate ('Power Pellets', Ethylene Control Inc., USA) to some of the tanks so as to maintain ethylene concentrations in the storage environment at the required levels.

2.3. Fruit quality evaluations

The fruit were assessed at harvest and following 3 months of cold storage. On both occasions, measurements were taken immediately and after 4 days of ripening at 20 °C. Initial measurements at harvest included starch clearance, total soluble solids (TSS), and titratable acidity (TA). Starch clearance was estimated by dipping a cut half of each fruit into a solution of iodine and potassium iodide. The surface area that did not stain due to starch clearing was visually estimated (0–100%). Each juice sample was made from a composite of wedges cut from five different fruit that were crushed in a press and filtered through cheesecloth. The TSS and TA of each juice sample were measured using a refractometer (Abbe model 10450, American Optical Corp., USA) and an automatic titrator (TIM850 Titralab, Radiometer Analytical, USA), respectively.

At each assessment, fruit quality was evaluated in terms of color, firmness, incidence and severity of scald, decay and internal breakdown. Color was measured using a Minolta Chroma Meter (Model CR300, Minolta Co., Japan) using the standard CIE illuminant in the $L^*a^*b^*$ mode. Color changes from green to yellow were indicated by calculating the hue angle (H°), from $\arctan b^*/a^*$. When taking flesh firmness measurements, the pear skin was removed on both sides of each fruit to allow two separate readings. Firmness was measured using an Ametek penetrometer (Western Industrial Supply Co., San Francisco, USA) mounted in a standard drill press and fitted with

an 8 mm probe. Measurements from fruit which had total internal breakdown were discarded. Scald, decay and internal breakdown were ranked subjectively as 0, none; 1, slight; 2, moderate; or 3, severe. The percentage of fruit that were affected by each of these disorders was also calculated for each treatment.

The results were analyzed using SAS statistical software (Version 7, SAS Institute Inc., USA) to conduct a series of factorial analyses of variance. Means were compared using Duncan's multiple range test to calculate the least significant difference for each data set ($\alpha = 0.05$). Data were analyzed by harvest date and by treatment, as well as by temperature and evaluation time.

3. Results

3.1. Initial measurements

There were no significant differences between the replicates, so the data were combined. Pears from the three harvest dates differed significantly in terms of their initial firmness and color, as well as starch, TSS and TA (Table 1). This confirmed that the pears were at different maturities when harvested. Early fruit were harder and greener than later fruit, with minimal starch clearing and high acidity. Later fruit contained less acid and starch and had higher TSS.

3.2. Ethylene concentrations

Ethylene production by fruit stored at 2 °C was such that it became difficult to keep the concentration around the fruit to the specified level. This was particularly true of the fruit stored with 1 and 5 $\mu\text{l l}^{-1}$ ethylene. Although there was considerable variation, the mean ethylene concentrations during storage were close to the required values (Table 2).

3.3. Firmness

The early season pears remained significantly firmer ($P < 0.0001$) than pears from either of the later two harvests when the pears were first removed from storage, regardless of storage tem-

Table 1
Initial attributes of pears from three different harvests

	Firmness (N)	Color (H°)	Starch (% cleared)	TSS (%)	TA (meq)
Sacramento-1	83.2 a	115.1 a	2 c	10.8 b	0.31 a
Mendocino-2	76.5 b	114.4 b	26 b	11.0 b	0.24 b
Mendocino-3	70.7 c	112.3 c	41 a	12.1 a	0.22 b

Table 2
Setpoints for ethylene concentrations inside tanks at -1 or 2 °C, compared with the mean ethylene concentrations achieved over the experimental period; values are \pm the standard error of the mean

Nominal value	-1 °C ($\mu\text{l l}^{-1}$)	2 °C ($\mu\text{l l}^{-1}$)
Control ($0 \mu\text{l l}^{-1}$)	0.10 ± 0.01	0.32 ± 0.04
$1 \mu\text{l l}^{-1}$	1.13 ± 0.06	1.38 ± 0.13
$5 \mu\text{l l}^{-1}$	5.00 ± 0.16	5.23 ± 0.32
$10 \mu\text{l l}^{-1}$	9.32 ± 0.48	9.28 ± 0.53

perature (Fig. 1). This difference was more strongly apparent in the pears stored at -1 °C

than in those at 2 °C. At -1 °C, harvest 1 fruit were nearly 12 N firmer than those from harvest 3, a difference similar to that observed at harvest. However, these variations between harvests disappeared once the pears were ripened.

Pears stored at 2 °C softened considerably more during storage than those kept at -1 °C (Fig. 1). However, during 4 days of ripening at 20 °C, it was the fruit that were stored at -1 °C that softened most. This meant that the fruit stored at -1 °C were edible-soft after the ripening period, whereas most of those stored at 2 °C were not. In part, this result was due to uneven softening by the fruit stored at 2 °C; some fruit were not measur-

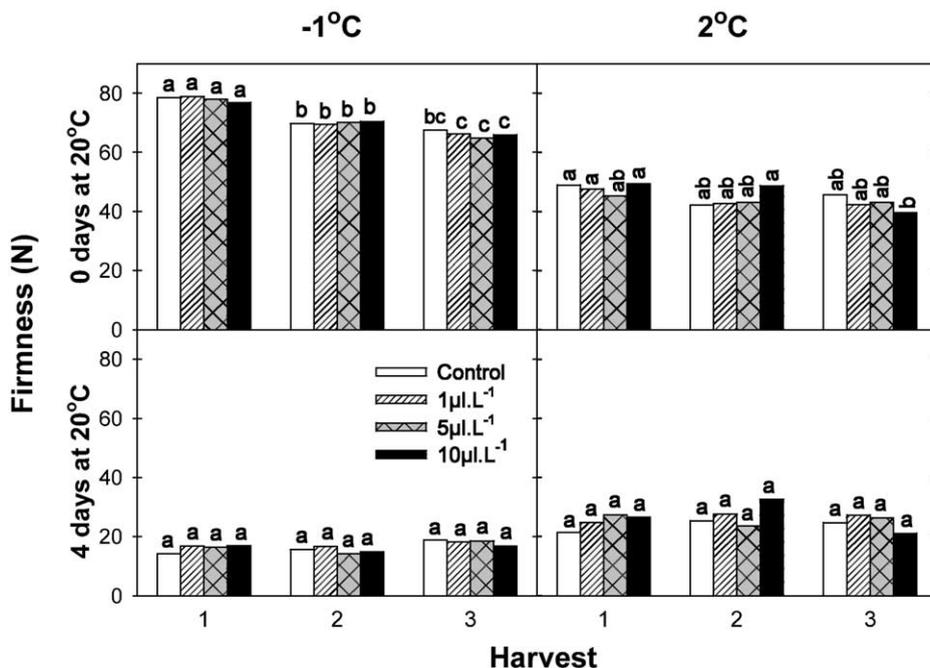


Fig. 1. Firmness of pears exposed to different concentrations of ethylene during 3 months of storage at -1 or 2 °C, both immediately after storage and after storage plus 4 days of ripening at 20 °C. Different letters indicate significantly different values for each temperature and evaluation time.

able because they had turned to pulp while others remained hard and inedible. Firmness was not significantly affected by the ethylene concentration in any of the temperature/ripening time combinations tested.

3.4. Color

Fruit stored at $-1\text{ }^{\circ}\text{C}$ for 3 months remained green. However, those at $2\text{ }^{\circ}\text{C}$ yellowed in storage (Fig. 2). All of the pears stored at $2\text{ }^{\circ}\text{C}$ were fully yellow upon removal from storage, having H° values below 100. The fruit that had been stored at $-1\text{ }^{\circ}\text{C}$ also reached full yellow color following the 4 days ripening period.

After the fruit stored at $2\text{ }^{\circ}\text{C}$ were moved to ambient temperatures, color change continued more rapidly in pears that had been exposed to ethylene than in those that had been kept in air ($P=0.0165$). The opposite effect was observed with pears stored with 5 or $10\text{ }\mu\text{l l}^{-1}$ ethylene at $-1\text{ }^{\circ}\text{C}$, which remained greener after 4 days ripen-

ing than air stored fruit ($P < 0.0001$). However, in both cases this difference was numerically small, being less than two units.

Color also varied between fruit from different harvest dates. Green color was retained best in fruit from harvest 1 stored at $-1\text{ }^{\circ}\text{C}$ relative to values at harvest, these remaining significantly greener both after storage and following 4 days ripening compared with those from subsequent harvests ($P < 0.0001$). When these same fruit were stored at $2\text{ }^{\circ}\text{C}$, they yellowed more after storage and ripening than pears from later harvests ($P < 0.0001$).

3.5. Scald and internal browning

Perhaps the most obvious difference between the storage temperatures was the incidence of physiological disorders. Most of the fruit stored at $2\text{ }^{\circ}\text{C}$ were moderately to severely scalded upon removal from storage (Fig. 3). The symptoms worsened when the fruit were kept for an addi-

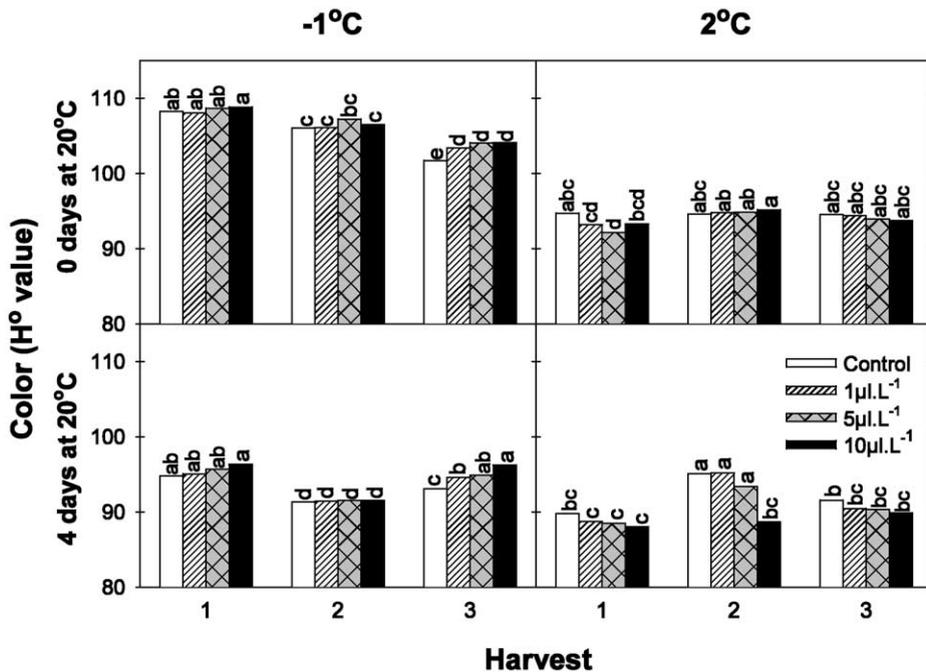


Fig. 2. Color of pears exposed to different concentrations of ethylene during 3 months of storage at -1 or $2\text{ }^{\circ}\text{C}$, both immediately after storage and after storage plus 4 days of ripening at $20\text{ }^{\circ}\text{C}$. Different letters indicate significantly different values for each temperature and evaluation time.

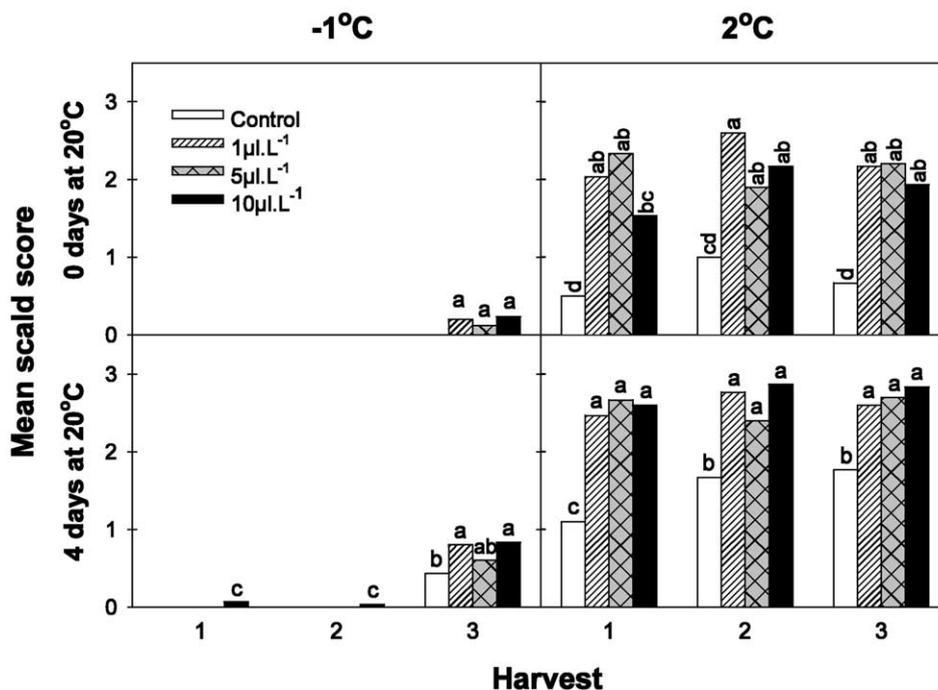


Fig. 3. Mean scald score of pears exposed to different concentrations of ethylene during 3 months of storage at -1 or 2 °C, both immediately after storage and after storage plus 4 days of ripening at 20 °C. Scald scores; 0, none; 1, slight; 2, moderate; 3, severe. Different letters indicate significantly different values for each temperature and evaluation time.

tional 4 days at 20 °C, after which none remained edible. In contrast, scald was almost entirely absent from fruit stored at -1 °C. Approximately 4% of fruit stored at -1 °C had evidence of scald symptoms upon removal from storage, compared with 67% of fruit stored at 2 °C. After ripening, these values remained significantly different, increasing to 20 and 94%, respectively ($P < 0.0001$).

Both the number of fruit affected and scald severity (score) were significantly increased by storage with ≥ 1 $\mu\text{l l}^{-1}$ ethylene at 2 °C ($P < 0.0001$). Whereas 99% of fruit stored with ≥ 1 $\mu\text{l l}^{-1}$ ethylene at 2 °C and ripened for 4 days at 20 °C were scald affected, approximately 79% of control fruit had symptoms of scald. At -1 °C, the effect of ethylene was less severe. In this case only the 10 $\mu\text{l l}^{-1}$ ethylene treatment consistently increased scald relative to the control. However, a similar trend was evident at lower levels of ethylene ($P = 0.131$), particularly for harvest 3 fruit (Fig. 3).

Scald development was also affected by harvest date. The disorder was almost entirely absent from the early and mid season fruit stored at -1 °C, with higher scald incidence on fruit from the final harvest. Less than 2% of fruit from the first two harvests were found to have scald following storage at -1 °C and 4 days ripening, compared with 58% of fruit from the final harvest. Even at 2 °C, fruit from harvest 1 had significantly less scald than pears from harvests 2 and 3 ($P < 0.0001$).

Storage at 2 °C also had a large effect on fruit internal quality. Severe internal breakdown occurred in many of the fruit stored at this temperature, but was virtually absent from those stored at -1 °C (Fig. 4). This became particularly obvious after ripening, by which time almost 100% of the fruit kept at 2 °C had moderate to severe internal breakdown.

During storage, the presence of ethylene increased internal breakdown in fruit stored at 2 °C

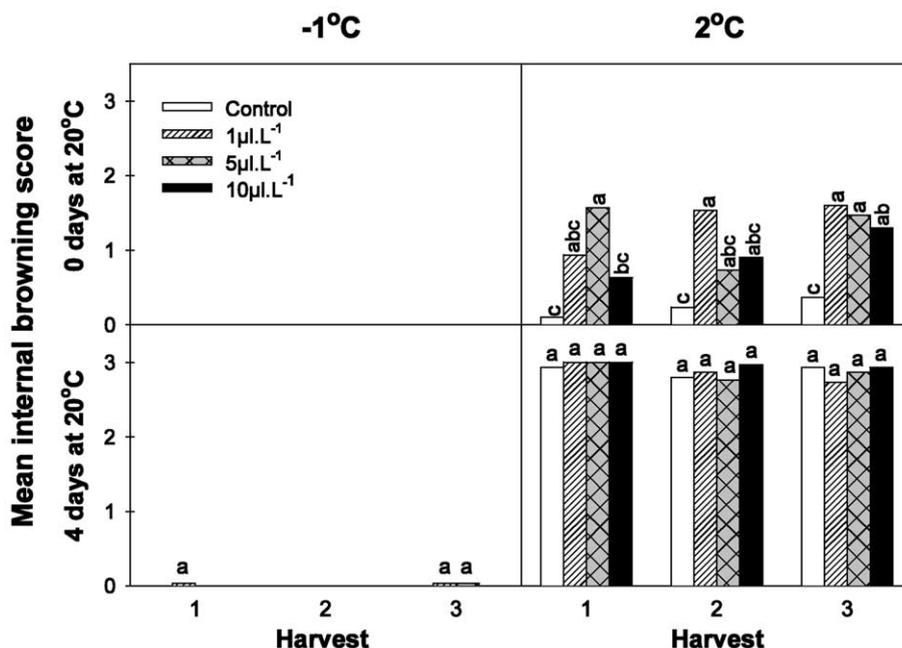


Fig. 4. Internal browning of pears exposed to different concentrations of ethylene during 3 months of storage at -1 or 2 °C, both immediately after storage and after storage plus 4 days of ripening at 20 °C. Internal browning scores; 0, none; 1, slight; 2, moderate, 3, severe. Different letters indicate significantly different values for each temperature and evaluation time.

compared with the controls ($P < 0.0001$). However, the severity of symptoms when fruit were assessed after ripening meant that these differences were no longer apparent. As with scald, internal breakdown appeared to be increased in later harvested fruit, although in this case the difference was not significant.

4. Discussion

When pears were stored at -1 °C they remained green during cold storage and ripened normally at 20 °C. Increasing the storage temperature to 2 °C resulted in fruit that were yellow, soft and had severe scald together with significant internal breakdown even when first removed from storage. Ma et al. (2000) reported similar differences in the quality of 'Cascade' pears after 2–5 months storage at -1 or 2 °C.

The condition of the fruit worsened after ripening, by which time none of the pears remained edible. Not only did the fruit stored at 2 °C ripen

unevenly, they also softened less at ambient temperatures than those held at -1 °C. This suggests that 3 months of storage at 2 °C damaged the pears' capacity to soften normally at ambient temperatures.

Ethylene in the storage environment further decreased the quality of pears stored at 2 °C. However, the extremely poor condition of pears kept at this temperature means that this difference would not be commercially significant. In contrast, pears stored at -1 °C ripened normally when transferred to 20 °C, irrespective of the ethylene concentration during storage. Ethylene significantly affected color of fruit stored at -1 °C, but the difference was numerically small and unlikely to have commercial significance. Similarly, although scald and internal breakdown were increased by exposure to ethylene at -1 °C, this effect was relatively small, especially in earlier harvested fruit. In general, it was evident that the effects of ethylene on fruit quality were minimal compared with the effects of temperature.

Wills and Warton (2000) have suggested that ethylene in the storage environment directly affects fruit quality. However, even the relatively high ethylene concentration of $10 \mu\text{l l}^{-1}$ had nominal effect on 'Bartlett pears' when the fruit were stored at their optimal temperature. This is in agreement with results reported by Retamales et al. (1998), who found little benefit in controlling ethylene during storage of 'Packham's Triumph' and 'Beurre Bosc' pears.

The effect of harvest date on the quality of stored pears has been previously reported. Incidences of superficial scald, flesh browning and core breakdown all increase with fruit maturity at harvest (Crisosto et al., 1994; Raese and Drake, 2000; Ma et al., 2000). It is interesting that the opposite effect can occur in apples, early harvested fruit often being more susceptible to superficial scald than more mature fruit (Watkins et al., 1995).

5. Conclusions

These results demonstrate that temperature control is a more important factor in maintaining pear quality than scrubbing ethylene. While it is certainly desirable to minimize ethylene concentrations around stored pears in order to reduce the incidence of scald and internal breakdown, from a practical standpoint it is important that this is not done at the expense of good temperature control. There was little difference between pears exposed to $1 \mu\text{l l}^{-1}$ and those exposed to $10 \mu\text{l l}^{-1}$, suggesting that very low concentrations would have to be achieved for there to be any benefit in terms of improved quality. The high rate of ethylene production by the fruit made it difficult to maintain ethylene concentrations at $\leq 1 \mu\text{l l}^{-1}$, especially at 2°C . In a commercial situation, where large amounts of fruit are packed tightly into cool stores, it is likely to be extremely challenging if not impossible to keep ethylene to such low levels.

Softening, yellowing, scald development and internal breakdown differed greatly between -1 and 2°C . Storage life of 'Bartlett pears' stored at 2°C is clearly less than the 3 months used in this

trial, whereas fruit held at -1°C ripened normally after this time. Further work is necessary to determine the critical temperature for storing pears above which excessive ripening and physiological damage will occur during long term storage. The interaction between temperature and the effects of ethylene should also be further defined, as it is clear that the effects of ethylene are quite different between temperatures as close as -1 and 2°C .

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