EFFECT OF CO_2 CONCENTRATION ON ETHYLENE PRODUCTION, ORGANIC ACID RETENTION, AND INTERNAL DISORDERS OF PEAR FRUIT IN LOW O_2 STORAGE

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For controlled atmosphere (CA) storage of pear fruit, it is reasonable to hypothesize that a greater beneficial effect on lengthening storage life could be accomplished by maintaining O_2 concentration in storage as low as possible and CO_2 concentration in storage as high as possible. However, an elevated CO_2 concentration in CA storage has resulted in increasing brown-core disorder of pear fruit after a prolonged storage (2, 8, 10). Low O_2 concentration at 1% in CA storage has been reported to lengthen storage life, prevent scald development, and maintain high dessert quality of `Bartlett', `Bosc', and `d`Anjou' fruit (4, 6, 13). Due to the possible development of brown-core disorder, CO_2 concentration in 1%O_2 as been recommended at less than 0.1% for the pear industry in the Pacific Northwest. However, the actual safe level of CO_2 concentration in 1%O_2 storage has not been studied for pear fruit in this region. The purposes of this report are to demonstrate the effect of CO_2 concentrations in 1%O_2 storage on ethylene production, organic acid retention, and brown-core development of `Bartlett' and `Bosc' pear fruit during or after a prolonged storage.

`Bartlett' and `Bosc' pear fruits (Pyrus communis, L.) were harvested at an optimum maturity based on the average flesh firmness of 80N and 62N respectively, from an orchard located at the Mid-Columbia Experiment Station, Hood River, Oregon in the 1983 season. Fruits were stored in 1%O_2 storage with different concentrations of CO_2 and in air at -1°C for 4 and 6 months respectively.

Ethylene Production

Ethylene production of pear fruits in different storages were measured weekly during the storage period. For `Bartlett' fruit, ethylene production of fruit in air storage increased rapidly from 0.03 $\mu l \cdot kg^{-1} \cdot hr^{-1}$ to about 10 $\mu l \cdot kg^{-1} \cdot hr^{-1}$ during the first 2 months of storage and then increased very little during the rest of storage period (Fig.1). Ethylene production of fruit stored in 1%O_2 without CO_2 was suppressed substantially as compared with air-stored fruit. It increased from 0.005 to 0.05 $\mu l \cdot kg^{-1} \cdot hr^{-1}$ during the first 2 months of storage and to about 3 $\mu l \cdot kg^{-1} \cdot hr^{-1}$ after 4 months (Fig. 1). This is not surprising as the requirement of O_2 for ethylene biosynthesis and action has been well documented (3, 7, 12, 15). Ethylene production in fruit stored in 1% O_2 was further suppressed by CO_2 level at 1% or higher. The average ethylene production of fruit stored in 1% O_2 plus CO_2 at 1~3% was only about 0.001 $\mu l \cdot kg^{-1} \cdot hr^{-1}$ during the first 2 months of storage and then increased to only about 0.3 $\mu l \cdot kg^{-1} \cdot hr^{-1}$ after 4 months (Fig. 1). CO_2 has been suggested as an effective antagonist to ethylene action (1, 3). The suppression of ethylene production in fruit by elevated CO_2 in 1% O_2 storage could be due to the inhibition of ethylene action by CO_2.

The schemes of ethylene production of 'Bosc' pear fruit stored in air and in 1% O_2 with different concentrations of CO_2 were quite similar to those of 'Bartlett' fruit. Fruits stored in air produced much higher ethylene during 6 months of storage as compared with those stored in 1% O_2 (Fig. 2). Elevated CO_2 in 1% O_2 storage also further suppressed the ethylene production (Fig. 2). In 1% O_2 storage, CO_2 concentrations at 1 to 1.5% almost suppressed the ethylene production of 'Bosc' fruit to a constantly low rate at less than 0.01 $\mu l \cdot kg^{-1} \cdot hr^{-1}$ throughout 6 months of storage (Fig. 2).

Theoretically, a lower rate of ethylene production of pear fruit during storage period implies a slower rate of senescent process. Thus, pear fruit stored in 1% O_2 with elevated CO_2 should have a longer storage life than those stored in 1% O_2 without CO_2. Likewise, pear fruit stored in 1% O_2 with or without CO_2 should have a longer storage life than those stored in air.

Organic Acids

Only 'Bartlett' fruits were used for this study. After 4 months of different storages, fruits were ripened at 20°C in air for 8 days. Changes in organic acids were determined on days 0, 2, 4, 6, and 8 of ripening period. Only malic, citric, and fumaric acids could be separated and quantified by the previously described method (5). Shikimic and succinic acids co-eluted as one peak and therefore could not be quantified. Fumaric acid presented only a trace amount in fruit analyzed so that it was not reported. Fruits stored in 1% O_2 without CO_2 for 4 months at -1°C retained a higher amount of malic and citric acids than those stored in air (Fig. 3 and 4). Fruits stored in 1% O_2 with CO_2 at 1% or above retained malic and citric acids even higher than those stored in 1% O_2 without CO_2 and in air (Fig. 3 and 4). During the 8-day ripening period, both malic and citric acids declined linearly regardless of the previous storage conditions. It was evident that fruit with high acidity at the end of storage would also retain high acidity upon ripening. High acidity in fruit has been suggested to contribute in part to the flavor retention upon ripening (14). The retention of organic acids in fruit stored in 1% O_2 with and without CO_2 might be due to slower overall metabolic activities or to CO_2 fixation via malic enzyme (9, 11).

Brown-Core Disorder

The major concern of CA storage with elevated CO_2 levels of pear fruit was the possible development of brown-core disorder. For 'Bartlett' fruit, the incidences of brown-core disorder were 1.2%, 1.2%, 2.4%, 6.9%, 16.9%, and 14.7% after 4 months of 1% O_2 storage with CO_2 concentrations at 0, 1, 1.5, 2, 2.5, and 3% respectively (Fig. 5). For 'Bosc' fruit, the incidences of brown-core disorder were 1.4%, 8.3%, 20.8%, 26.0% and 32.5% after 6 months of 1% O_2 storage with CO_2 concentrations at 0, 0.1, 0.5, 1.0, and 1.5% respectively (Fig. 6). It was evident that 'Bartlett' fruits were less susceptible to brown-core disorder than 'Bosc' fruits. Since fruits stored in 1% O_2 without CO_2 also developed some incidence of disorder symptom, it was possible that the brown-core disorder was partially due to the effect of low O_2 and that the elevated CO_2 concentrations interacted with 1% O_2 to enhance the incidence of disorder.

According to a fruit inspector for pear fruit, 5% of pear fruit per a packed box (i.e., a 20-kg box) with brown-core disorder would be considered as commercially unacceptable (personal communication). Thus, for 'Bartlett' fruit, the safe low O_2 storage regime would be at 1% O_2 with CO_2 between 0 and 1.5%; and for 'Bosc' fruit, it would be only at 1% O_2 with trace CO_2 (i.e. 0.03% or less).

Conclusions

Ethylene production of 'Bartlett' and 'Bosc' pear fruit was suppressed by 1% O_2 during storage at -1°C. Elevated CO_2 concentrations in 1% O_2 further suppressed ethylene production. The slower rate of ethylene production of pear fruit during storage period implied a slower rate of senescent process and thus a longer storage life. Fruit stored in 1% O_2 without CO_2 retained a higher content of organic acids than those stored in air. Fruit stored in 1% O_2 with elevated CO_2 retained even higher content of organic acids than those stored in 1% O_2 with trace CO_2 and in air. The retention of high organic acid content in fruit after a prolonged CA storage indicated that the dessert quality was preserved. Both 'Bartlett' and 'Bosc' fruits stored in 1% O_2 developed brown-core disorder regardless of CO_2 levels in the storage; but the incidence was enhanced when CO_2 concentration in 1% O_2 storage was above 2% for 'Bartlett' fruit and 0.1% for 'Bosc' fruit. Based on the susceptibility of fruit to brown-core disorder, the safe low O_2 regime would be 1% O_2 with CO_2 between 0 and 1.5% for 'Bartlett' fruit, and 1% O_2 with trace CO_2 for 'Bosc' fruit grown in the Hood River district of Oregon.

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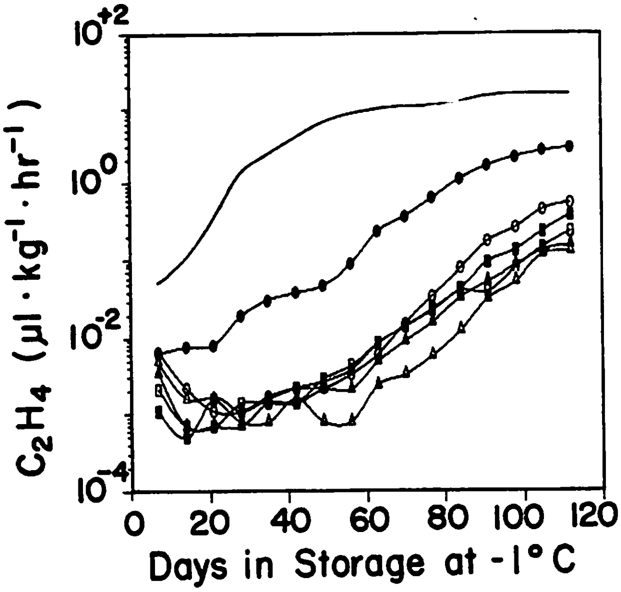

Fig. 1. Ethylene productions of 'Bartlett' pears stored in 1% O_2 with CO_2 concentrations at 0% (●), 1% (○), 1.5% (■), 2% (□), 2.5% (▲), and 3% (△); and in air (—) at -1°C during 4 months of storage.

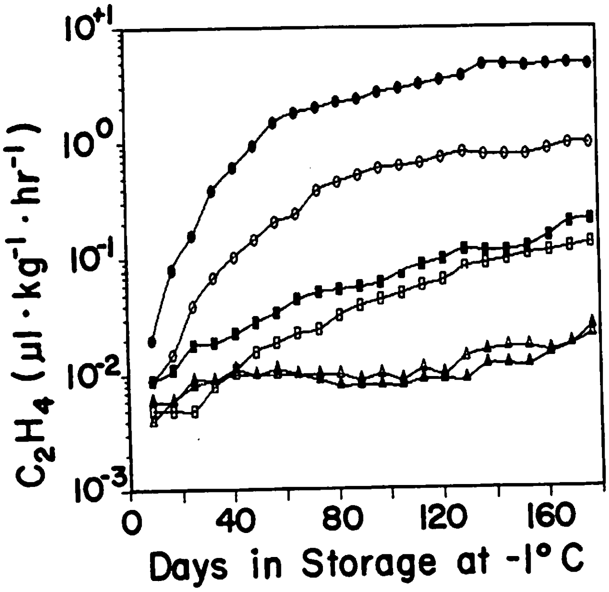

Fig. 2. Ethylene productions of 'Bosc' pears stored in 1% O_2 with CO_2 concentrations at 0% (○), 0.1% (■), 0.5% (□), 1% (▲), and 1.5% (△); and in air (●) at -1°C during 6 months of storage.

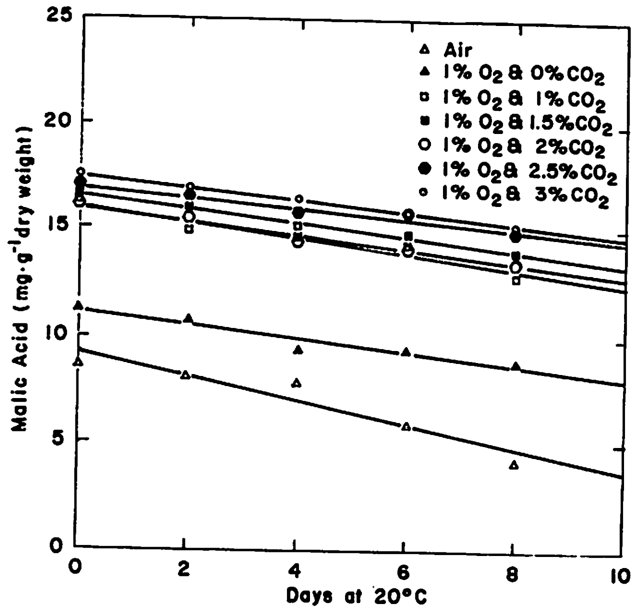

Fig. 3. Changes in malic acid in 'Bartlett' pears during 8 days of ripening at 20 C. Fruits had been stored at -1 in 1% O_2 with different concentrations of CO_2 and in air for 4 months.

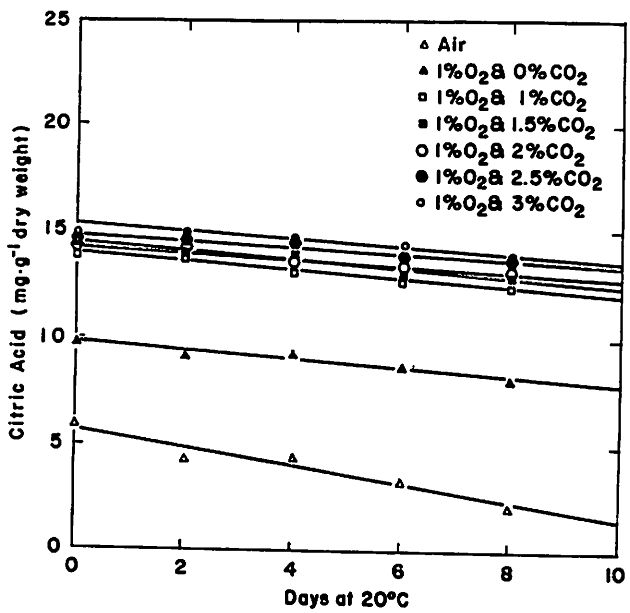

Fig. 4. Changes in citric acid in 'Bartlett' pears during 8 days of ripening at 20°C. Fruits had been stored at -1 in 1% O_2 with different concentrations of CO_2 and in air for 4 months.

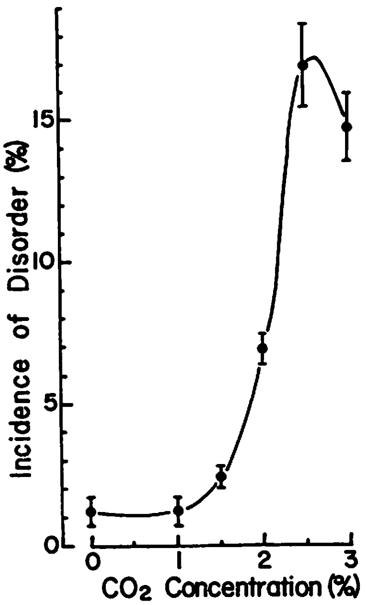

Fig. 5. Incidence of brown-core disorder of 'Bartlett' pears after 4 months of storage at -1°C in 1% O_2 with different concentrations of CO_2. Fruits stored in air were free from brown-core disorder after 4 months of storage.

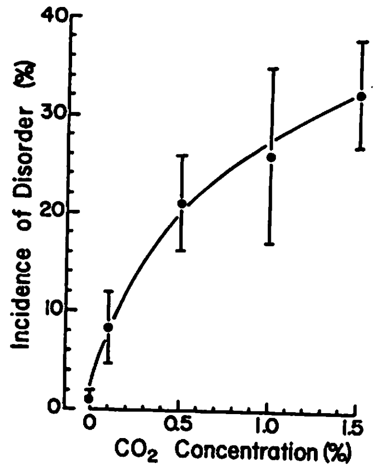

Fig. 6. Incidence of brown-core disorder of 'Bosc' pears after 6 months of storage at -1°C in 1% O_2 with different concentrations of CO_2. Fruits stored in air were free from brown-core disorder after 6 months of storage.