sponse between time and initial treatments was quadratic (Fig. 2). The greatest increase in mold count was for fruit that had been RA-cooled without SO_2 fumigation, followed by FA-cooled without SO_2, RA-cooled with SO_2, and least in FA-cooled with SO_2.

Comparison of means for day 8 data showed only that the mold count was significantly higher in the RA-cooled fruit with and without fumigation than in the FA-cooled fruit with fumigation (Table 1). The mold counts were all under the 50%-positive field count level used as a guide for commercial acceptability (1). Mold counts for the commercially produced puree prepared from stored fruit were similar to those for the subsamples on day 8 (Table 1).

At the time of processing, the fruit that were not sulfured did not possess a characteristic strawberry odor. Botrytis rot had developed in the fruit, mainly under the cap. There was essentially no SO_2 in the subsamples of fruit on days 4 and 8 or in the puree. However, on day 2, the fruit treated with SO_2 had an average level of 15.5 $mg \cdot kg^{-1}$ — a level sufficiently high to control rot in grapes (10).

Analysis of data indicated that there was a significant change (quadratic response, 34.1 to 36.7 to 35.1 $mg \cdot 100\ g^{-1}$) in anthocyanin content during cold storage. The increase over time was probably the result of anthocyanin development in the mature green to partially ripe fruit during the cooling process. The method of cooling and the use of a fumigant did not have an effect on anthocyanin content. Analysis of data for the degradation index indicated that there was little or no oxidation throughout the storage period.

The pH of the fruit from subsamples increased and the total acid content decreased slightly between storage days 0 and 8, but the changes were not statistically significant. The level of soluble solids remained constant throughout the storage interval.

All samples of puree and jam prepared from puree were found to have acceptable appearance, color, texture, and flavor (Table 2). Although there were some significant differences, no sample had significantly improved organoleptic attributes for all the variables used to measure quality.

These studies indicate that mechanically harvested strawberries for processing can be stored in bulk bins for up to 8 days using either RA- or FA-cooling to remove field heat. However, in view of a steady increase in the mold count and the quantity of moldy fruit, some loss of yield of usable end product can be expected as storage time increases, particularly for fruit that are RA-cooled. For maximum yield of high quality processed product, RA-cooled fruit should not be stored in bulk bins for more than 4 to 6 days and FA-cooled fruit for not more than 6 to 8 days. Fumigation with SO_2 does not appear to be a necessity for storing mechanically harvested fruit in bulk bins for up to 8 days if the fruit are FA-cooled, but the treatment does provide some protection to RA-cooled fruit.

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Low-ethylene CA Storage of 'McIntosh' Apples in a Semi-commercial Sized Room

F.W. Liu[1], J.R. Turk[2], D. Samelson[2], and D.J. Kenyon[3]

Department of Pomology, Cornell University, Ithaca, NY 14853

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Abstract. **'McIntosh' apples (*Malus domestica* Borkh.) sprayed with 1000 or 2000 $mg \cdot liter^{-1}$ daminozide in July 1982 were harvested in September and stored in a semi-commercial sized, low-ethylene controlled atmosphere (CA) room at 2.2 to 3.3°C until May 1983. An ethylene scrubber containing 45 kg of potassium permanganate–alumina beads and a blower kept the ethylene concentration below 0.05 $\mu l \cdot liter^{-1}$ throughout the storage period. Fruit samples were taken out of storage periodically for quality and shelf life evaluations. Most of the apples taken out in Apr. 1983 were still preclimacteric. Apples stored in the low-ethylene CA until May lost only 3.5% of their original flesh firmness. Comparable apples lost 24.2% of firmness in a commercial CA storage without ethylene scrubbing. During a 6-day holding period in air at 20°, the rates of softening of apples from both low-ethylene and commercial CA storage were substantially faster than the rate of softening of freshly harvested apples. Chemical names used: butanediolic acid mono(2,2-dimethylhydrazide) (daminozide).**

Several recent reports have indicated significant benefits of ethylene removal in CA storage of apples. Knee and Hatfield (3) found that ethylene removal decreased the flesh softening and reduced the superficial scald of 'Bramley's Seedling' apples. Blanpied et al. (2) reported success in low-ethylene CA storage of 'Empire' apples. Lidster et al. (5) found some benefit of ethylene removal for 'McIntosh' apples stored in 3% O_2 + 5% CO_2, but not for those stored in 1% O_2. Liu (6) demonstrated that daminozide-sprayed 'McIntosh' apples could be stored in flow-through low-ethylene CA for 7.5 months without a significant loss of firmness. However, nondaminozide 'McIntosh' apples softened significantly in a similar storage system. Knee et al. (4) also found that daminozide-sprayed 'Cox's Orange Pippin' apples were firmer than unsprayed apples after low-ethylene CA storage. Successful results of simulated low-ethylene CA storage of daminozide-sprayed 'McIntosh' apples in repeated observations during the last few years (1, 7, 9) further suggested a trial low-ethylene CA storage in a semi-commercial size room.

Mature, standard size 'McIntosh' apple trees at the Cornell Univ. orchard were sprayed with either 1000 or 2000 $mg \cdot liter^{-1}$ daminozide (Alar-85, Uniroyal Chemical, Naugatuck, Conn.) on 15 July 1982. Several trees left unsprayed were used for apple maturity evaluations and are referred to as control trees in this paper.

In the maturity evaluation, 10 apples were collected from each of the 3 representative control trees at 3-day intervals beginning in early Sept. 1982. The internal ethylene of

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[1]Associate Professor.

[2]Research Technicians.

[3]Orchard Manager.

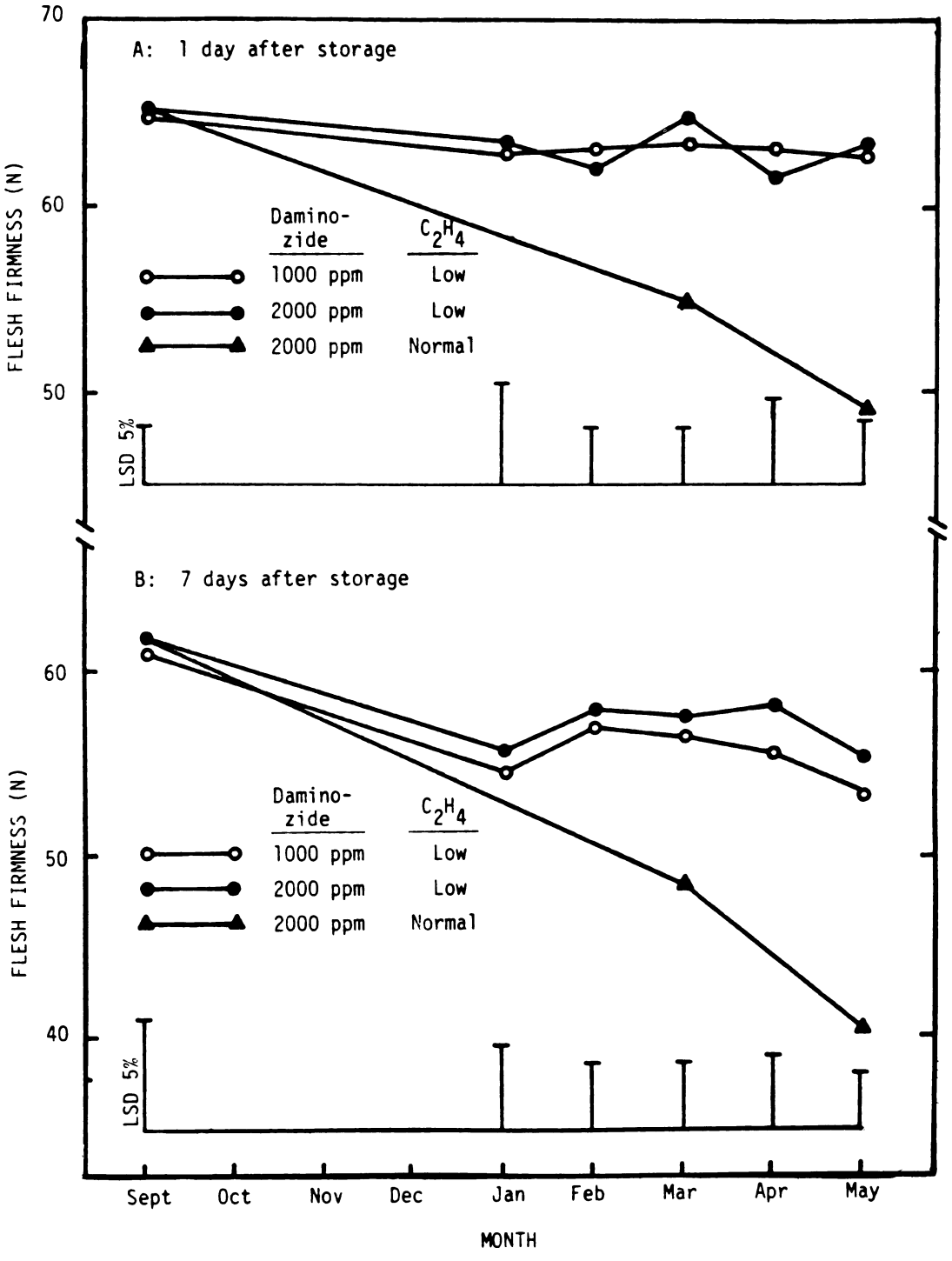

Fig. 1. Firmness changes of daminozide-sprayed 'McIntosh' apples in low-ethylene and commercial CA. **A** and **B**: firmness measured one and 7 days after the apples were placed in air at 20°C, respectively. Data presented are means of triplicate samples, 20 apples per sample.

each apple was measured with a previously described method (9). The earliest date when at least 10% of apples representing at least 2 trees contained ≥0.2 μl·liter^{-1} ethylene was 9 Sept.; this was interpreted as the date of the onset of autocatalytic ethylene production (AEP). Previous observations indicated that daminozide-sprayed 'McIntosh' apples responded favorably to low-ethylene CA if they were harvested within 10 days after the onset of AEP in control apples.

Daminozide-sprayed apples were harvested on 15–16 Sept. i.e., 6 to 7 days after the onset of AEP in the control apples. Apples harvested from 6 representative trees, 3 sprayed with 1000 mg·liter^{-1} and 3 sprayed with 2000 mg·liter^{-1} daminozide, were used for periodic observations of quality changes in storage. Fruits from individual trees were used as replicates. Forty apples from each tree were kept in paper bags, 20 apples per bag, and placed at 20°C in air for firmness measurements one and 7 days after harvest. The remaining apples were put into boxes at about 20 kg per box. Five boxes from each of the 6 trees were stored in a semi-commercial size, low-ethylene CA room and 2 boxes from each of the 3 trees sprayed with 2000 mg·liter^{-1} daminozide were stored in a commercial CA room with normal ethylene levels. Apples from other trees sprayed with 2000 mg·liter^{-1} daminozide were harvested into bulk bins, about 400 kg per bin, and used to fill the balance of the low-ethylene CA room. All apples for storage were kept at the storage temperature beginning at the day of harvest.

The semi-commercial size low-ethylene CA room had an inside dimension of 8 m × 4.6

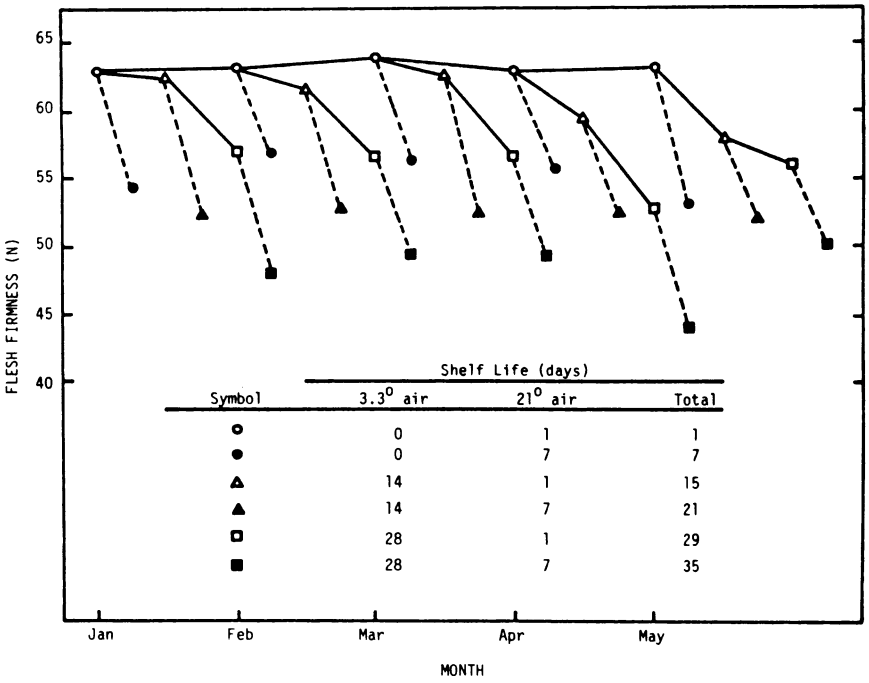

Fig. 2. Firmness changes of poststorage 'McIntosh' apples in shelf life tests at 3.3° and 20°C. The apples had been sprayed with 1000 mg·liter^{-1} daminozide and stored in low-ethylene CA. Data presented are means of triplicate samples, 20 apples per sample.

m × 4.3 m (height), and held about 30 metric tons of apples. A metal ethylene scrubber, 46 cm × 61 cm × 183 cm (height), containing 45 kg of potassium permanganate–alumina beads (Purafil, Atlanta, Ga.) in 2 layers and a 22.3 m^3·min^{-1} capacity blower, was placed in the room. The blower forced the room atmosphere through the Purafil layers and discharged it back into the room. The room was sealed on 17 Sept. and was slowly purged with N_2 for 3 days to reduce its O_2 concentration to 3%. Thereafter, the room was operated at 2.2–3.3°C, 90–95% RH and a desired atmosphere of 2% to 3% O_2 plus 3% CO_2 for the first month and 2% to 3% O_2 plus 5% CO_2 after the first month with <1 μl·liter^{-1} ethylene throughout the storage period. The O_2 and CO_2 concentrations were monitored daily with an Orsat gas analyzer. Ethylene was monitored several times per month with a gas chromatograph. The O_2 and CO_2 concentrations fluctuated only slightly from the desired levels. The average O_2 and CO_2 concentrations were 2.6% and 3.2%, respectively, for the first month an 2.8% and 4.4%, respectively, for the rest of storage period. The ethylene concentration was 0.23 μl·liter^{-1} on 22 Sept. just before the scrubber was turned on. The scrubber was operated continuously from 22 Sept. 1982 to 1 May 1983. The ethylene concentration dropped to 0.02 μl·liter^{-1} on 23 Sept. 1982, remained at ≤0.02 μl·liter^{-1} until 4 Mar. 1983, and then gradually increased to 0.04 μl·liter^{-1} by 1 May.

The commercial CA storage, where 2 boxes each of the 3 trees sprayed with 2000 mg·liter^{-1} daminozide were stored, was operated by a grower. The desired CA condition was the same as in the low-ethylene CA room, except the O_2 level was reduced more slowly and ethylene was not scrubbed. The exact temperature, humidity, and atmospheric composition data were not available, except that the ethylene concentration measured in Mar. 1983 was 900 μl·liter^{-1}.

One box of apples from each of the 6 trees were removed from the low-ethylene CA room at 4-week intervals beginning 10 Jan. and ending 2 May 1983 for quality and shelf-life evaluations. One box of apples from each of the 3 trees was removed from the commercial CA room on 10 Mar. and on 3 May 1983. Six 20-apple samples were selected from each box and placed in 6 paper bags immediately after the box was removed from a CA room and transferred into air. The quality of the samples was evaluated one sample at a time after the sample was kept at 3.3°C for 0, 14, or 28 days and at 20° for 1 or 7 days, as tubulated in Fig. 3. In the quality evaluation, the flesh firmness, soluble solids content, and acidity of the apples were evaluted with previously described methods (9).

In order to measure the rates of respiration and ethylene production, 21 apples from each of the 6 trees were removed from the low-ethylene CA on 11 Apr. 1983 and placed in three 3.8-liter glass jars, 7 apples per jar, kept at 20°C. With flow-board control, fresh air flowed through each jar at 200 ml·min^{-1} for 7 days. The CO_2 concentrations in the effluent air were measured daily with an infrared analyzer (Beckman Model 864) and the ethylene measured with a gas chromatograph.

The low-ethylene CA room was opened on 2 May 1985. Six 20-apple random samples from 6 bins were kept in air at 20°C for one day, and another 6 similar samples were kept at 20° for 7 days. Then the samples were evaluated for the flesh firmness, soluble solids, and acidity with the procedure mentioned previously.

The flesh firmness of 'McIntosh' apples sprayed with 1000 and 2000 mg·liter^{-1} daminozide was the same (about 65 N) at harvest, and it changed little in the low-ethylene CA storage from Sept. 1982 to May 1983 (Fig. 1A). The mean firmness loss of these apples in the 7.5-month low-ethylene CA storage was only 3.5%. Every apple evaluated one day after removal from the low-ethylene CA room had or exceeded the most desirable firmness (58 N) for 'McIntosh' found by Liu and King (8). On the other hand, the mean firmness of apples stored in a commercial CA storage decreased from 65 N at harvest to 55 N by Mar. 1983 and to 49 N by may 1983 (Fig. 1A).

Freshly harvested apples only lost an average firmness of 3.5 N during 6 additional days (from the 2nd to the 7th day) of holding in air at 20°C, but apples after 7.5 months of CA storage lost an average firmness of 7.0 N (range from 3.3 to 9.5 N) during the same holding period (Fig. 1 A and B). Although firm low-ethylene CA apples softened more markedly than less-firm high-ethylene CA apples in another experiment (9), the firmness losses of apples from low-ethylene and commercial CA storage in this experiment were similar during the 6-day holding period (Fig. 1). Therefore, the firmness difference between apples stored in low-ethylene and commercial CA persisted until after the holding period (Fig. 1).

Apples removed from low-ethylene CA storage on and after 10 Jan. 1983 lost an average firmness of 2.3 N (range: 0.3–4.8 N) in a 14-day holding period and lost an average firmness of 7.3 N (range: 6.0–10.2 N) in a 28-day holding period in air at 3.3°C (Fig. 2). These apples seemed to have fairly good shelf life when kept refrigerated.

The soluble solids levels were 12.1%, 12.2%, and 11.6% in Mar. 1983, and were 12.4%, 12.1%, and 11.4% in May 1983 for apples sprayed with 1000 or 2000 mg·liter^{-1} daminozide and stored in low-ethylene CA, and apples sprayed with 2000 mg·liter^{-1} daminozide and stored in commercial CA, respectively. The differences were not statistically significant at the 5% level. The acidity changes in apples from harvest to Jan. 1983 was not known because the acidity at harvest was not measured. The acidity of all apples gradually declined after January (Fig. 3). The acidity of apples stored in low-ethylene CA was slightly higher than that of apples stored in commercial CA in May 1983 (Fig. 3).

Most apples stored in low-ethylene CA until 11 Apr. 1983 were still in the preclimacteric condition, as estimated by their low rates of CO_2 and ethylene production. The rates of CO_2 production were low one day after the apples were moved from low-ethylene CA to air at 20°C. The rates gradually increased and reached a high plateau 4 days later (Fig. 4). Among the 18 jars of apples (7 apples per jar) only one jar, which contained apples sprayed with 1000 mg·liter^{-1} daminozide,

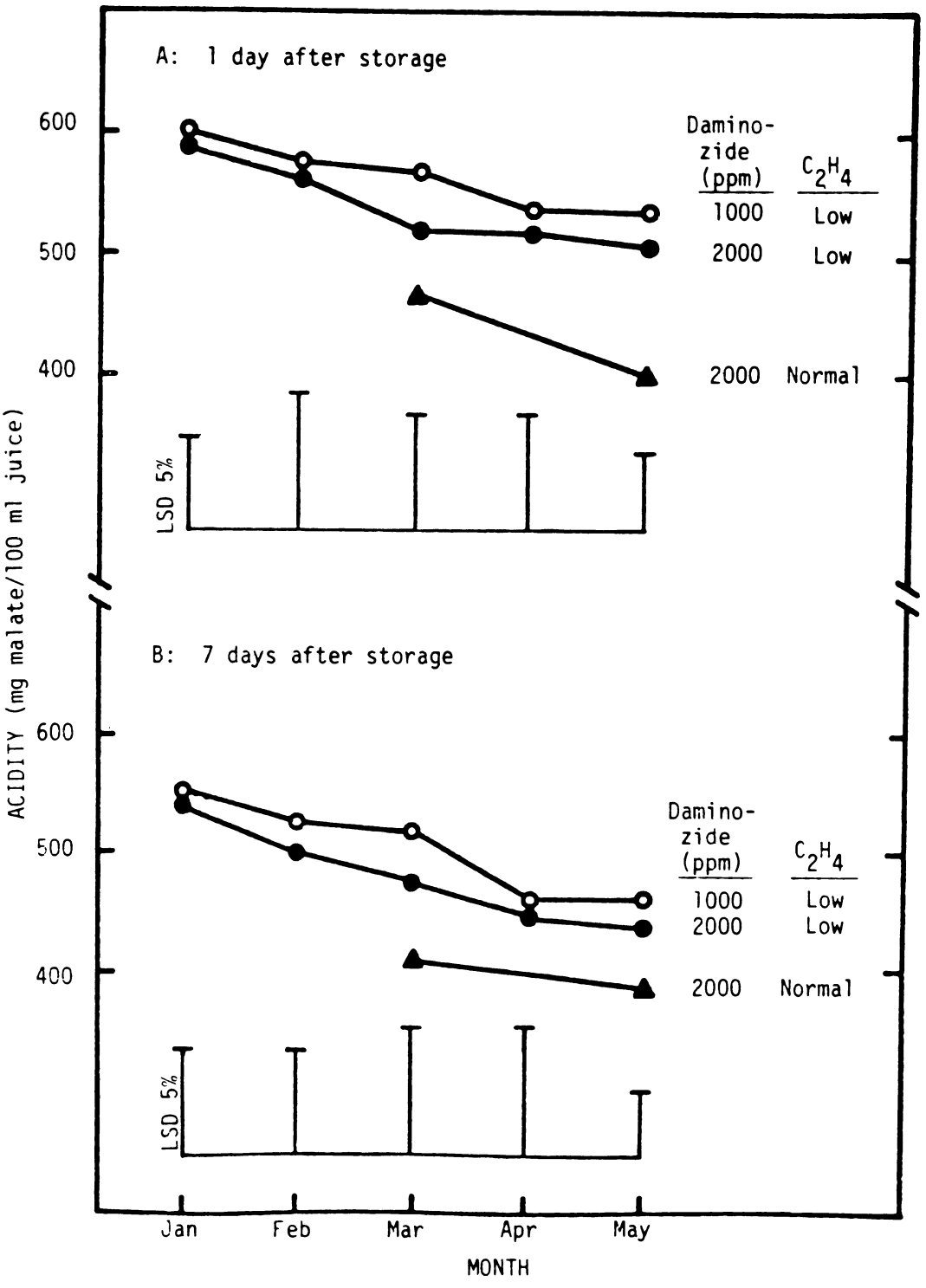

Fig. 3. Acidity changes of daminozide-sprayed 'McIntosh' apples in low-ethylene and commercial CA. **A** and **B**: acidity measured one and 7 days after the apples were placed in air at 20°C, respectively. Data presented are means of triplicate juice samples, each extracted from wedges of 20 apples.

produced a trace (although measurable) amount of ethylene (0.65 $\mu l \cdot kg^{-1} \cdot hr^{-1}$) on the day when the apples were moved from low-ethylene CA to 20°C. Three jars of apples, which were sprayed with 1000 $mg \cdot liter^{-1}$ daminozide, produced a measurable amount of ethylene one day later, and all 18 jars produced measurable ethylene 2 days later. The rates of ethylene production continued to increase thereafter (Fig. 4).

Of the 120 apples randomly taken from 6 bins in the low-ethylene CA room on 2 May 1983 and held one day in air at 20°C, 110 apples (92%) had a firmness of ≥60 N (Fig. 5). The softest apple had a firmness of 57.8 N, which was a very desirable firmness for 'McIntosh' (8). These apples, however, lost an average firmness of 11 N during the additional 6 days of holding in air at 20° (Fig. 5). During the holding period at 20°, these apples softened more rapidly than the apples selected from 20-kg boxes, which lost an average firmness of 7.0 N, as mentioned previously. The apples stored in bins and boxes were harvested from different trees. The sample fruits selected from bins were larger in size than fruits selected from boxes as judged visually. Whether these differences were the causes of different softening rates could not be verified. Nevertheless, the result indicated that the firm low-ethylene CA 'McIntosh' tended to soften rapidly in warm air. Therefore, continuous refrigeration will be desirable for low-ethylene CA 'McIntosh' apples.

When the Purafil in the ethylene scrubber was examined at the end of storage, <10% of the 45-kg Purafil has changed color from pink to brown. According to this estimation,

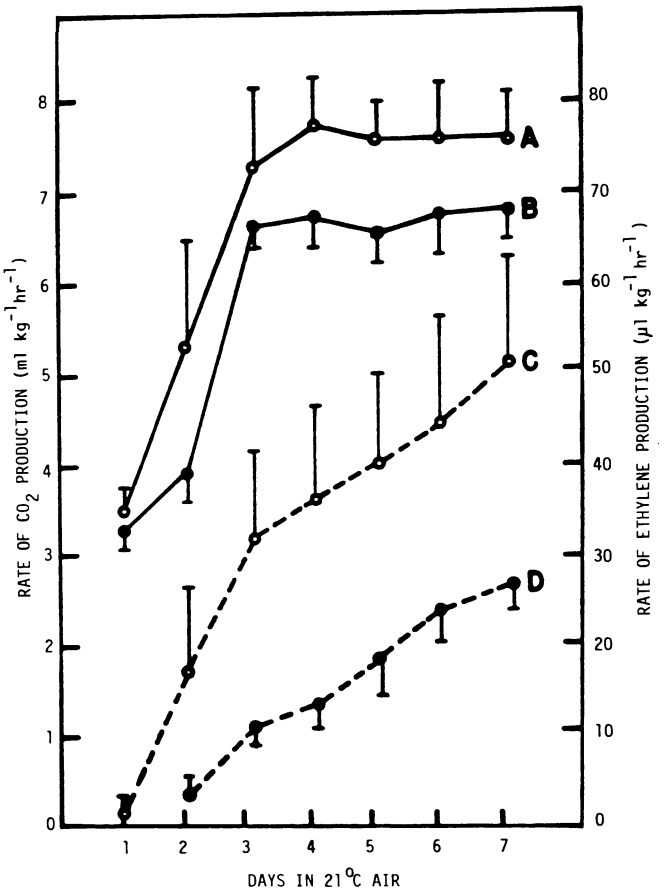

Fig. 4. Rates of CO_2 and C_2H_4 production of 'McIntosh' apples that had been stored in low-ethylene CA from Sept. 1982 to Apr. 1983 and then transferred to 20°C air. **A** and **B**: rates of CO_2 production of apples sprayed with 1000 and 2000 mg·liter^{-1} daminozide, respectively. **C** and **D**: rates of C_2H_4 production of apples sprayed with 1000 and 2000 mg·liter^{-1} daminozide, respectively. Data presented are means of 3 replicate (trees), 21 apples per replicate, with SE of the mean.

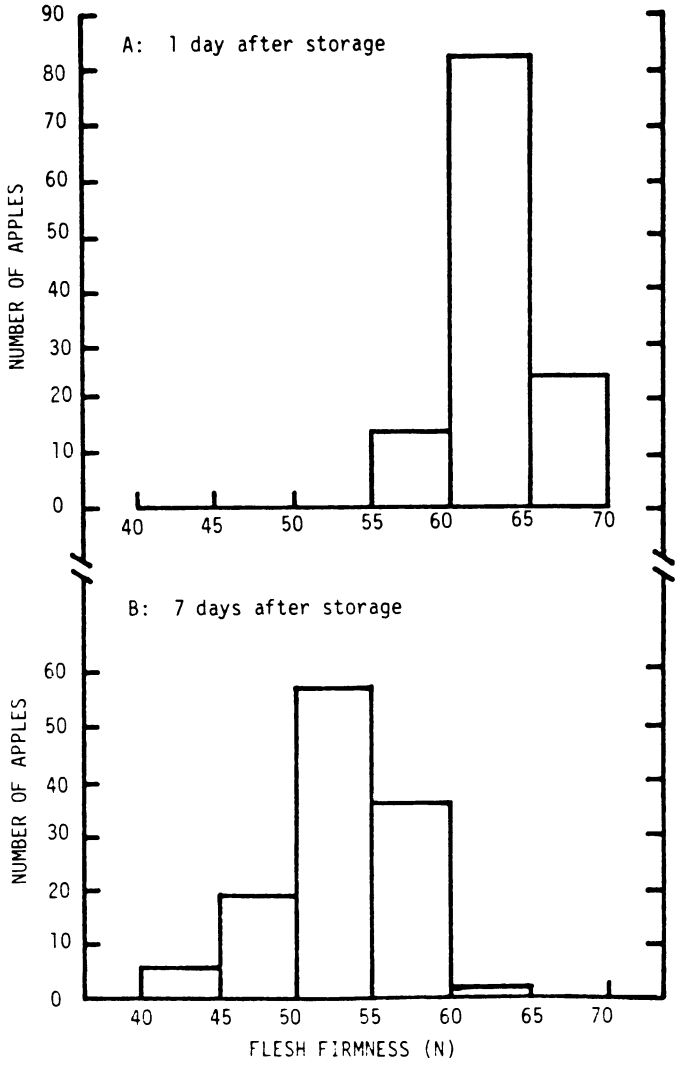

Fig. 5. Firmness of 'McIntosh' apples that had been sprayed with 2000 mg·liter^{-1} daminozide and stored in low-ethylene CA from 16 Sept. 1982 to 2 May 1983 followed by one or 7 days of holding in air at 20°C. Apples were randomly taken from 6 bins in the storage.

<4.5 kg equivalent of Purafil was actually spent in scrubbing the ethylene produced by some 30 MT of daminozide-sprayed 'McIntosh' apples stored in the low-ethylene CA for 7.5 months. This estimation of the small amount of ethylene absorbent needed for the low-ethylene CA storage was supported by the fact that most of the fruit samples removed from the storage in Apr. 1983 produced little ethylene immediately after the removal (Fig. 4). The rates of ethylene production of daminozide-sprayed 'McIntosh' apples also remained low until April in simulated low-ethylene CA storage in other experiments (9).

The nearly 30 MT of remaining low-ethylene CA apples, which were not used for quality evaluations, were sold at the Cornell orchard in May 1983. There was much praise on the firmness and freshness, but some criticism on the lack of tree-ripe 'McIntosh' apple flavor and red color from the customers.

The results of this experiment suggest that it is possible to keep the firmness and freshness of 'McIntosh' apples for 7.5 months in low-ethylene CA storage. The procedure includes a midsummer tree-spray with daminozide, harvest date determination based on the internal ethylene of nondaminozide apples, and continuous ethylene removal from storage.

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