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Ethylene and Temperature Effects on Softening and White Core Inclusions of Kiwifruit Stored in Air or Controlled Atmospheres

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Abstract. **The effects of C_2H_4 concentration, duration and timing of exposure to C_2H_4, and temperature on storage performance of kiwifruit (*Actinidia chinensis* Planch. 'Hayward') kept in air or a controlled atmosphere (CA) of 2% O_2 + 5% CO_2 were investigated. The presence of 0.05, 0.1, 0.5, 1.0, or 5.0 $\mu l \cdot liter^{-1}$ C_2H_4 in CA accelerated softening and induced white core inclusions (WCI) which increased with storage time and C_2H_4 concentration. There was no difference between a 2-week or a 4-week exposure to 0.5 $\mu l \cdot liter^{-1}$ C_2H_4 at the beginning of CA storage in the extent of softening or WCI incidence and severity, but prolonged exposures accelerated deterioration. The softening rate of kiwifruit kept in air or CA increased with temperature. The incidence and severity of WCI were much greater in fruit kept in CA + 0.5 $\mu l \cdot liter^{-1}$ C_2H_4 at 0° or 2.5°C than in fruit stored at 5° or 10°.**

Detrimental effects of C_2H_4 on kiwifruit kept in air or controlled atmospheres (CA) have been reported (1, 2, 8). Although CA can extend the storage life of kiwifruit at 0°C to 6 months or longer (2, 3, 8, 11), the presence of C_2H_4 under CA conditions significantly reduces the value of CA. In addition to accelerating fruit softening, C_2H_4, when combined with elevated CO_2 can induce some physiological disorders (2). We have shown that the white core inclusions (WCI) disorder occurred in the presence of 0.5 $\mu l \cdot liter^{-1}$ C_2H_4 and CO_2 (3% to 7%) and increased in severity with the increase of CO_2 concentration (2).

The deleterious effects of C_2H_4 in CA storage have been reported for apples (7). Compositional changes and the incidence and severity of certain physiological disorders have been related to interactions between storage temperature and atmospheric composition for apples (6, 9, 10, 12, 14), potato (13), and lettuce (4).

The objectives of this research were to: 1) evaluate the effects of C_2H_4 concentration, and duration and timing of exposure to C_2H_4 on flesh softening and WCI incidence and severity in kiwifruit kept at 0°C in CA (2% O_2 + 5% CO_2), and 2) study the interactions between temperature and exposure to C_2H_4 upon the postharvest deterioration of kiwifruit during storage in air or CA.

Materials and Methods

Effect of C_2H_4 concentration on softening and development of WCI during CA storage. Kiwifruit ('Hayward' cultivar) were harvested (at a soluble solids contents of about 7%) during the 1980 season from a commercial planting in Gridley, Calif., and transported to the Postharvest Pomology Research Facility at the Univ. of California at Davis. The fruit were dipped in a combination of 600 $\mu l \cdot liter^{-1}$ sodium-orthophenylphenate and 1125 $\mu l \cdot liter^{-1}$ 2,6 dichloro-4-nitroaniline at pH 11.0 to mini-

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mize decay during subsequent storage (15). The fruit were sorted to eliminate obvious defects and then cooled overnight to 0°C.

After cooling, fruit were placed either in vented polyethylene bags for air storage in a room with low C_2H_4 (<0.015 $\mu l \cdot liter^{-1}$) contamination or in 1.5 m^3 CA storage chambers. The desired treatments of CA (2% O_2 + 5% CO_2) or CA + C_2H_4 at 0.05, 0.1, 0.5, 1.0, or 5.0 $\mu l \cdot liter^{-1}$ were attained within 24 hr by a flow-through system (500 $ml \cdot min^{-1}$). The storage atmospheres were monitored by gas chromatography and maintained within 5% of the desired levels. The average C_2H_4 concentrations during 24 weeks of storage for those fruit stored in either "C_2H_4-free" air or CA were 0.01 and 0.004 $\mu l \cdot liter^{-1}$, respectively. In all treatments, the relative humidity was maintained at 90% to 95%.

At periodic intervals (2, 4, 6, 8, 12, 16, 20, and 24 weeks) fruit were removed from storage, warmed to 20°C and evaluated within 2 hr. Twenty-five fruit were evaluated for flesh firmness, visual quality, titratable acidity (TA), and soluble solids content (SSC). An additional 25 fruit were transferred to 20° and 95% RH for 7 days, then firmness (15 fruit), visual quality (25 fruit), TA, and SSC again were evaluated.

Two flesh firmness measurements were taken per pared fruit using a U.C. Firmness Tester (8-mm tip); individual fruit were considered as replicates for statistical analyses. Lengthwise wedges of tissue from each fruit were collectively juiced for TA and SSC determinations. An American Optical Refractometer with automatic temperature compensation was used to measure SSC. TA was determined by titrating 6 g juice with 0.1 NaOH to pH 8.2 and expressed as percentage of citric acid. All fruit were evaluated for the presence of WCI (2). Severity evaluation was made using the following scoring system: 0 = none, 1 = slight, 2 = moderate, and 3 = severe.

Effect of timing on C_2H_4 exposure during CA storage on softening and development of WCI. Fruit were harvested (at a SSC of about 8%) in 1981 from the same commercial planting and handled as described above. After cooling overnight at 0°C, the fruit were placed into 1.5 m^3 CA chambers. There were 5 treatments: CA (2% O_2 + 5% CO_2) for 24 weeks; CA plus 0.5 $\mu l \cdot liter^{-1}$ C_2H_4 for 24 weeks, CA plus C_2H_4 for 2 weeks followed by CA for 22 weeks, CA plus C_2H_4 for 4 weeks followed by CA for 20 weeks, and CA for 2 weeks followed by CA + C_2H_4 for 22 weeks. The desired CA atmosphere was established and maintained as described above. The average C_2H_4 concentration in the "C_2H_4-free" CA treatments was 0.005 $\mu l \cdot liter^{-1}$.

At periodic intervals (4, 6, 8, 12, 16, 20, and 24 weeks), fruit were removed from storage for determination of flesh firmness and ripening. After ripening, the incidence and severity of WCI were evaluated as described previously.

Effect of temperature on storage performance in air or CA with or without C_2H_4. Fruit were harvested (at a SSC of about 8%) in 1981 from the same commercial planting and handled as described above. After cooling overnight to 0°, 2.5°, 5°, or 10°C, the fruit were either placed into 1.5 m^3 CA chambers or into vented polyethylene liners for air storage. At each temperature there were 4 treatments: air, air plus 0.5 $\mu l \cdot liter^{-1}$ C_2H_4, CA (2% O_2 + 5% CO_2), and CA plus 0.5 $\mu l \cdot liter^{-1}$ C_2H_4. The CA treatments were attained and monitored as described above. The average C_2H_4 concentration around the fruit in the vented polyethylene liners kept in air was 0.011, 0.012, and 0.017, and 0.012 $\mu l \cdot liter^{-1}$ at 0°, 2.5°, 5°, and 10°, respectively. The average C_2H_4 concentration ($\mu l \cdot liter^{-1}$) in the "C_2H_4-free" CA was 0.006 at 0° and 2.5°, 0.007 at 5°, and 0.011 at 10°.

At periodic intervals, which depending upon the storage temperature and treatment, fruit were removed for flesh firmness, SSC, and TA determination and for ripening as described previously. Upon removal from storage and after ripening fruit were examined for WCI incidence and severity as described.

Results and Discussion

Effects of C_2H_4 concentration on softening and development of WCI during CA storage. Ethylene accelerated the softening of kiwifruit kept in CA in proportion to concentrations between 0.05 and 5.00 $\mu l \cdot liter^{-1}$ (Fig. 1). Exposure to 0.5 $\mu l \cdot liter^{-1}$ or higher concentrations of C_2H_4 resulted in significantly (P = 0.01) softer fruit as compared to the "C_2H_4-free" CA treatment after 12 weeks of storage. Fruit exposed to 0.5, 1.0, or 5.0 $\mu l \cdot liter^{-1}$ C_2H_4 in CA eventually softened to the level of fruit kept in air by the 24th, 20th, or 12th week of storage, respectively. Fruit exposure to 0.05 or 0.1 $\mu l \cdot liter^{-1}$ C_2H_4 resulted in significantly (P = 0.01) softer fruit as compared to the "C_2H_4-free" CA treatment after 16 weeks at 0°C.

Gatti (5) showed that symptoms of mechanical injury in kiwifruit are accentuated once flesh firmness drops below 22.2 N (5 lbf). Using this guideline and allowing for softening that may occur during distribution, we used 26.7 N as a cut-off point for maximum storage duration when comparing the treatments. The time required for fruit to soften to this point was 3 weeks in air, 8 weeks in CA + 5 $\mu l \cdot liter^{-1}$ C_2H_4, 12 weeks in CA + 0.5 or 1.0 $\mu l \cdot liter^{-1}$ C_2H_4, 16 weeks in CA + 0.1 $\mu l \cdot liter^{-1}$ C_2H_4, 24 weeks in CA + 0.05 $\mu l \cdot liter^{-1}$ C_2H_4, and longer than 24 weeks in "C_2H_4-free" CA.

Patterns of SSC and TA changes during air and CA storage of kiwifruit have been reported (2, 3, 11). There was no difference between treatments with regard to the pattern of change in SSC or TA (data not presented). In all the CA plus C_2H_4

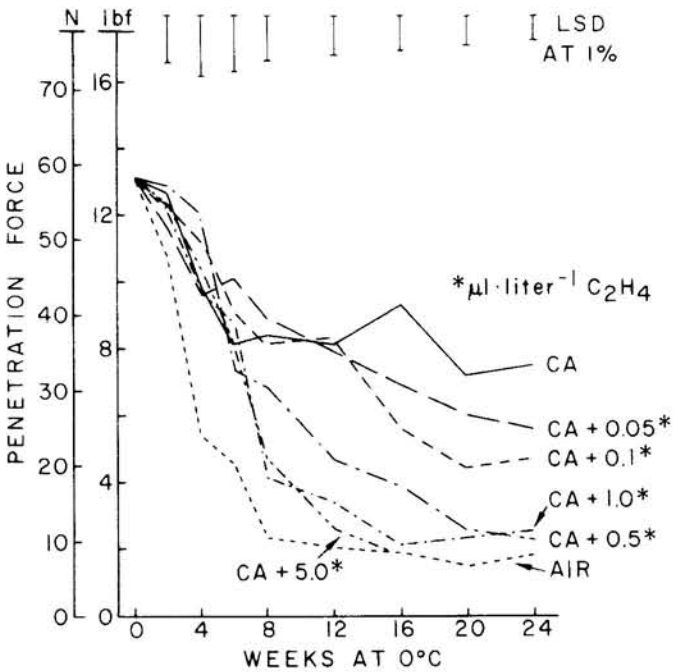

Fig. 1. Kiwifruit softening during storage at 0°C in air, CA (2% O_2 + 5% CO_2), or CA + C_2H_4 at 0.05, 0.1, 0.5, 1.0, or 5.0 $\mu l \cdot liter^{-1}$. LSD values shown were calculated based on a 1-way analysis of variance.

treatments, the appearance of WCI corresponded to the rise in SSC during storage.

In all the CA plus C_2H_4 treatments, WCI were noted by the 4th week of storage; however, the occurrence and severity of WCI were dependent upon C_2H_4 concentration (Fig. 2). WCI incidence and severity increased rapidly after the 4th week and remained at a constant level between 6 and 24 weeks in the 3 higher C_2H_4 concentrations (Fig. 2A). Fruit exposed to 0.1 $\mu l \cdot liter^{-1}$ C_2H_4 during CA storage showed an intermediate response in terms of both incidence and severity of WCI. In the presence of 0.05 $\mu l \cdot liter^{-1}$ C_2H_4, the percentage of WCI incidence continued to increase throughout storage but severity remained at a low level. A comparison of the rate of appearance of WCI (Fig. 2B) suggest that the response to C_2H_4 approximates Michealis-Menton kinetics.

Effect of timing of C_2H_4 exposure during CA storage on softening and development of WCI. A 2-week delay in C_2H_4 exposure delayed softening by 2 to 4 weeks, although once softening began, the decrease in firmness paralleled the softening curve for those fruit stored continuously in CA + C_2H_4. After 16 weeks of storage, there was no significant difference between these 2 treatments (Fig. 3). Fruit exposed to C_2H_4, 2 or 4 weeks at the beginning of storage were softer than fruit kept in "C_2H_4-free" CA after 8 weeks in storage. There was no consistent trend in differences between fruit from the 2 treatments.

When exposure to C_2H_4 was delayed 2 weeks, a corresponding 2-week delay in the appearance and development of WCI were observed (Fig. 4). However, the 2-week delay in C_2H_4 exposure made no difference after 12 weeks in storage when

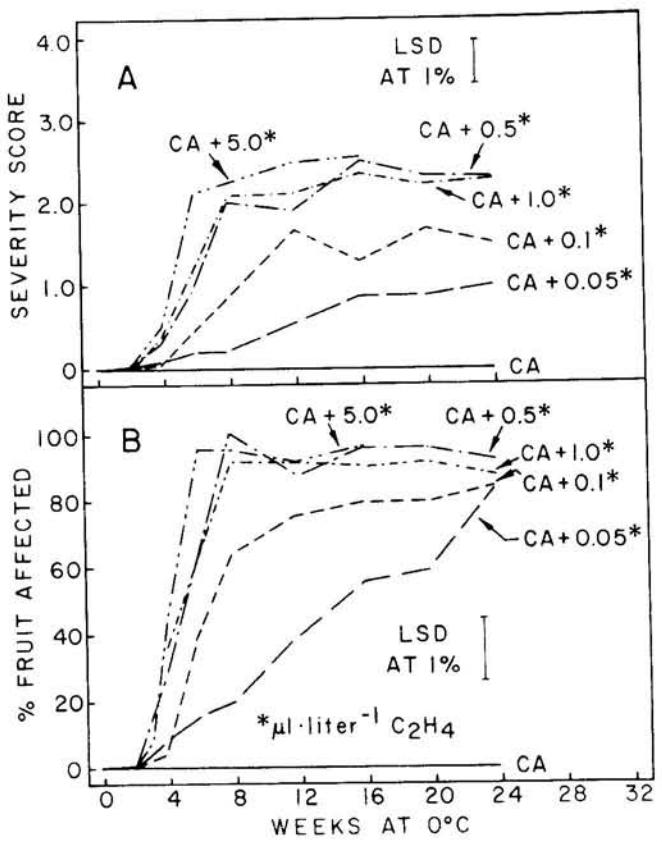

Fig. 2. WCI severity **(A)** and incidence **(B)** during 24 weeks of 0°C storage in CA (2% O_2 + 5% CO_2) or CA + C_2H_4 at 0.05, 0.1, 0.5, 1.0, or 5.0 $\mu l \cdot liter^{-1}$. Fruit evaluations were made after 2, 4, 6, 8, 12, 16, 20 and 24 weeks at 0°C plus 7 days in air at 20°. Severity score 0 = none, 1 = slight, 2 = moderate, and 3 = severe. LSD values shown were calculated based on a 2-way analysis of variance.

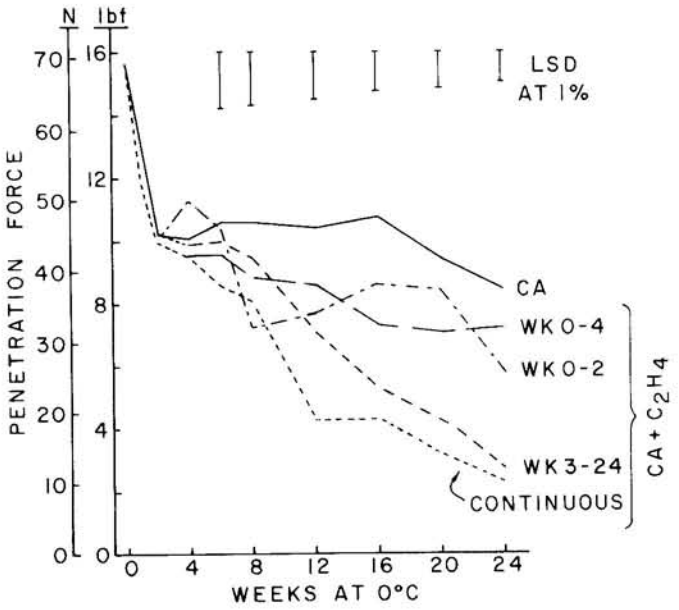

Fig. 3. Kiwifruit softening at 0°C in CA (2% O_2 + 5% CO_2) or CA + C_2H_4 (0.5 $\mu l \cdot liter^{-1}$) applied continuously or for specific periods (week 0–2, week 0–4, week 3–24) during storage. LSD values were calculated based on a 1-way analysis of variance.

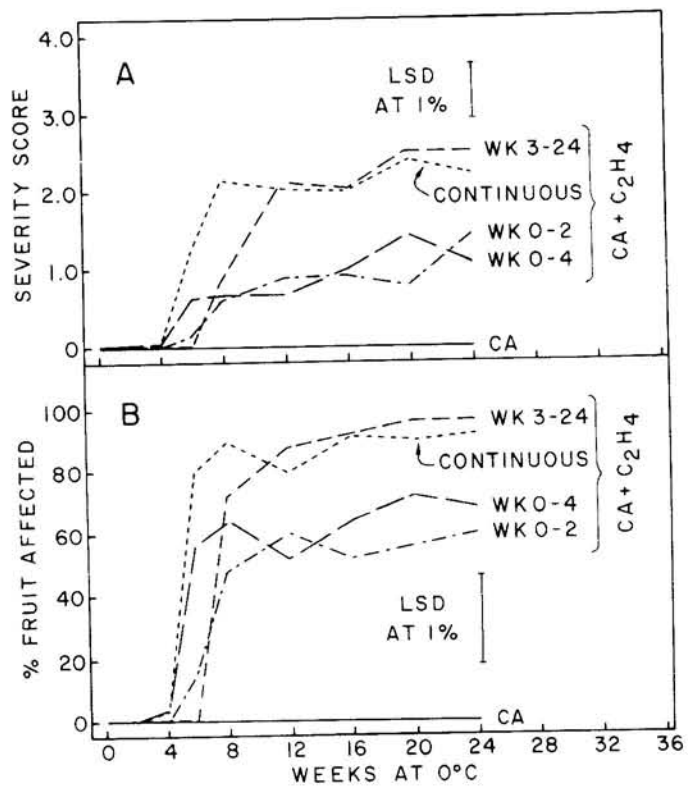

Fig. 4. WCI severity **(A)** and occurrence **(B)** during 24 weeks of 0°C storage in CA (2% O_2 + 5% CO_2) or CA + C_2H_4 (0.5 $\mu l \cdot liter^{-1}$) applied continuously or for specific periods (week 0–2, week 0–4, week 3–24) during storage. Fruit evaluations were made after 4, 6, 8, 12, 16, 20, and 24 weeks at 0° plus 7 days in air at 20°. LSD values shown were calculated based on a 2-way analysis of variance.

compared to the continuous C_2H_4 exposure treatment. When fruit were exposed to C_2H_4 for short durations (2 and 4 weeks) at the beginning of storage there was an intermediate response, implying that continuous exposure to C_2H_4 is not required for WCI development. In a subsequent test (data not shown), when C_2H_4 (0.5 $\mu l \cdot liter^{-1}$) during CA was delayed 10 weeks, very low levels of WCI developed. These data indicate that WCI can be induced by C_2H_4 + CO_2 combination at any time during CA storage at 0°. However, the severity of WCI is usually greater when exposure to C_2H_4 occurs during the first few weeks of CA storage. In general, the longer the duration of exposure to C_2H_4 during CA storage, the greater the incidence and severity of WCI.

Effect of temperature on storage performance in air or CA with or without C_2H_4. In air storage ("C_2H_4-free") the rate of softening increased with temperature during 12 weeks of storage (Fig. 5). The addition of 0.5 $\mu l \cdot liter^{-1}$ C_2H_4 to air storage reduced the time to attain a flesh firmness of 26.7 N (6 lbf) by 53%, 50%, 38%, and 75% at 0°, 2.5°, 5°, 10°C, respectively (Table 1).

For fruit kept in CA or CA + C_2H_4, there was a consistent trend in softening patterns between fruit stored at 5° or 10°C and those kept at 0° or 2.5° after 4 weeks in storage. Fruit stored at 5° or 10° softened much more rapidly than fruit kept at 0° and 2.5° (Fig. 5). The latter 2 treatments were statistically different (P = 0.01) from each other after 6 weeks of storage. Exposure to C_2H_4 in CA reduced the time to attain a flesh firmness of 26.7 N by >57%, 66%, 74%, and 78% in fruit kept at 0°, 2.5°, 5°, and 10°, respectively (Table 1). At all temperatures, CA retarded the softening rate of kiwifruit (Fig. 5 and Table 1).

In general, the pattern of SSC and TA changes did not appear to be influenced greatly by either treatment or storage temperature (data not presented). There was a trend of a more rapid rise in SSC at 10°C in air plus 0.5 $\mu l \cdot liter^{-1}$ C_2H_4 although this difference was not statistically significant (P = 0.05).

The incidence and severity of WCI in CA + C_2H_4 were temperature dependent (Fig. 6). Although the WCI disorder was observed at both 5° and 10°C, it never exceeded 12% of the number of evaluated fruit. WCI appeared first in fruit stored at 2.5°, but there was no difference in either severity or occurrence after 8 weeks of storage between fruit kept at 2.5° or 0°.

The interactions among temperature, time, and CA in relation to incidence and severity of physiological disorders have been demonstrated in apples (6, 9, 10, 12, 14) and lettuce (4). Our results indicate a trend that is generally similar to CO_2-induced brown stain on lettuce, which increases with the decrease in temperature from 10°C to 0°C (4). Since kiwifruit is not sus-

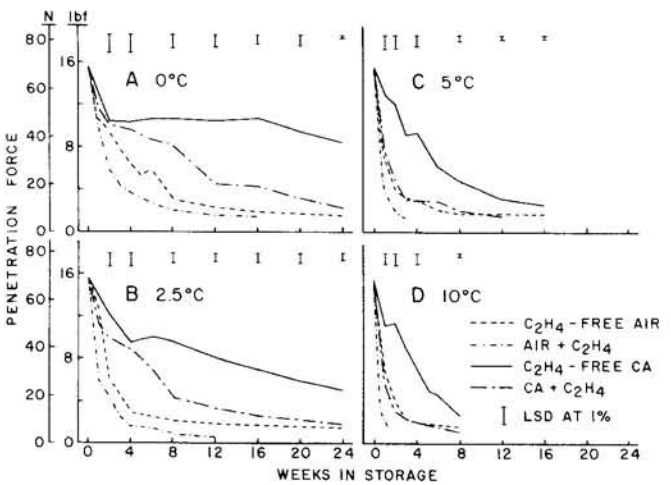

Fig. 5. Kiwifruit softening during storage at 0°, 2.5°, 5°, or 10°C in air or CA (2% O_2 + 5% CO_2) with or without the addition of 0.5 $\mu l \cdot liter^{-1}$ C_2H_4. LSD values shown were calculated based on a 1-way analysis of variance.

Table 1. Softening rate, as indicated by the number of weeks required to soften to an average (n = 25) flesh firmness of 26.7 N, of Kiwifruit stored under several temperatures and atmospheric compositions.[z]

Storage temperature (°C)	Weeks to a flesh firmness of 26.7 N (6 lbf)			
	Air	Air + C_2H_4[y]	CA[x]	CA[x] + C_2H_4[y]
0	4.3	2.0	>24.0	10.3
2.5	2.0	1.0	20.0	6.8
5	1.3	0.8	6.2	1.6
10	1.2	0.3	4.5	1.0

[z]Also see Fig. 5.
[y]0.5 $\mu l \cdot liter^{-1}$ C_2H_4.
[x]CA = 2% O_2 + 5% CO_2.

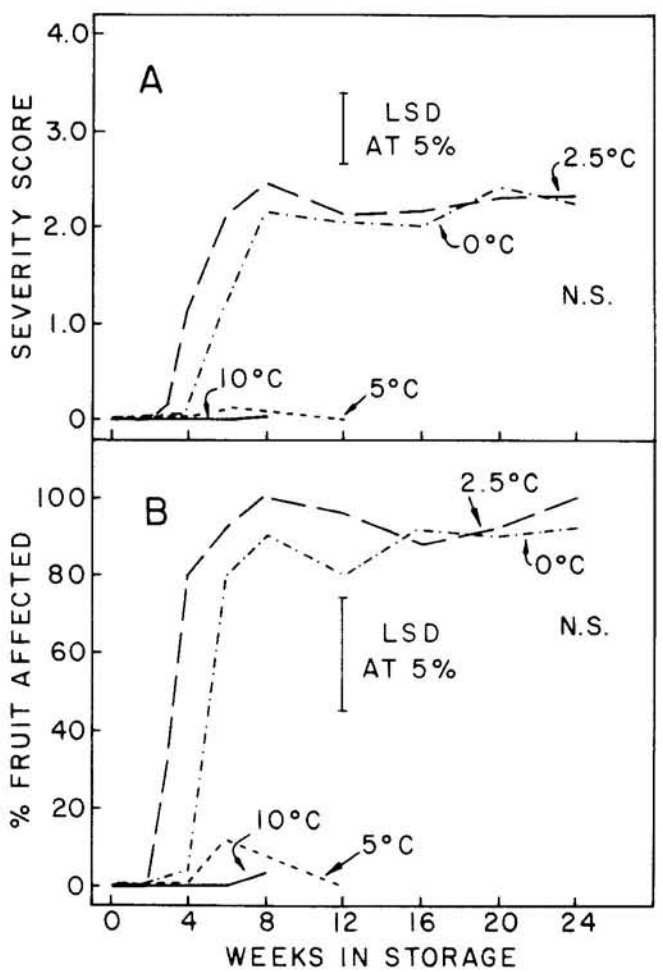

Fig. 6. WCI severity (**A**) and occurrence (**B**) during storage at 0°, 2.5°, 5°, or 10°C in CA (2% O_2 + 5% CO_2) with the addition of 0.5 $\mu l \cdot liter^{-1}$ C_2H_4. Fruit evaluations were made after 1, 2, 3, 4, 6, 8, 12, 16, 20, and 24 weeks storage plus 7 days in air at 20°. LSD values shown were calculated based on a 2-way analysis of variance.

ceptible to chilling injury, the effect of low temperatures on aggravating WCI may be due to increased solubility of CO_2 and/or other factors that increase susceptibility of the fruit to this physiological disorder.

Conclusions. Temperature during both air and CA storage plays an important role in determining the softening rate and the presence of C_2H_4 accelerates this process. WCI incidence and severity are dependent upon interactions among temperature, CO_2 concentration, and C_2H_4 concentration and timing of exposure during storage of kiwifruit. The kiwifruit appears to be more susceptible to WCI development during the first few weeks of storage at 0° or 2.5°C in CA. Future studies of WCI in kiwifruit should concentrate on understanding the biochemical basis of this disorder. This understanding would aid in identifying the role of each factor (C_2H_4, CO_2, low temperature) in the WCI development.

On the basis of results reported here, we recommend that harvested kiwifruit should promptly be cooled to 0°C and immediately stored at the same temperature in 2% O_2 + 5% CO_2 with C_2H_4 excluded and/or removed to maintain its concentration below 0.05 $\mu l \cdot liter^{-1}$. These procedures are essential to firmness retention and maximizing storage-life of kiwifruit.

Literature Cited

1. Arpaia, M.L., F.G. Mitchell, A.A. Kader, and G. Mayer. 1982. The ethylene problem in modified atmosphere storage of kiwifruit, p. 331–335. In: D.G. Richardson and M. Meheriuk (eds.). Proc. 3rd Natl. Controlled Atmosphere Res. Conf., Timber Press, Beaverton, Or.
2. Arpaia, M.L., F.G. Mitchell, A.A. Kader, and G. Mayer. 1985. Effects of 2% O_2 and varying concentrations of CO_2 with or without C_2H_4 on the storage performance of kiwifruit. J. Amer. Soc. Hort. Sci. 110(2):200–203.
3. Arpaia, M.L., F.G. Mitchell, G. Mayer, and A.A. Kader. 1984. Effects of delays in establishing controlled atmospheres on kiwifruit softening during and following storage. J. Amer. Soc. Hort. Sci. 109(6):768–770.
4. Brecht, P.E., A.A. Kader, and L.L. Morris. 1973. Influence of postharvest temperature on brown stain of lettuce. J. Amer. Soc. Hort. Sci. 98(4):399–402.
5. Gatti, R. 1984. Susceptibility of kiwifruits to mechanical injury at harvest and during storage. MS Thesis. Univ. of California, Davis.
6. Knee, M. and M. Bubb. 1975. Storage of Bramley's Seedling Apples. II. Effects of source of fruit, picking data and storage conditions on the incidence of storage disorders. J. Hort. Sci. 50:121–128.
7. Liu, F.W. 1978. Effects of harvest date and ethylene concentration in controlled atmosphere storage on the quality of 'McIntosh' apples. J. Amer. Soc. Hort. Sci. 103(3):388–392.
8. McDonald, B. and J.E. Harman. 1982. Controlled atmosphere storage of kiwifruit. 1. Effect on fruit firmness and storage life. Scientia Hort. 17:113–123.
9. Meheriuk, M., O.L. Lau, and J.W. Hall. 1984. Effects of some postharvest and storage treatments on the incidence of flesh browning in controlled-atmosphere-stored 'Delicious' apples. J. Amer. Soc. Hort. Sci. 109(3):290–293.
10. Meheriuk, M. and S.W. Porritt. 1973. Effects of picking date, delayed storage, storage temperature and storage atmosphere on the quality of Starking Delicious apples. Can. J. Plant Sci. 53:593–595.
11. Mitchell, F.G., M.L. Arpaia, and G. Mayer. 1982. Modified-atmosphere storage of kiwifruits (*Actinidia chinensis*), p. 235–238. In: D.G. Richardson and M. Meheriuk (eds.). Proc. 3rd Natl. Controlled Atmosphere Res. Conf. Timber Press, Beaverton, Ore.
12. Porritt, S.W. and M. Meheriuk. 1973. Influence of storage humidity and temperature on breakdown in Spartan apples. Can. J. Plant Sci. 53:597–599.
13. Sherman, M. and E.E. Ewing. 1983. Effects of temperature and low oxygen atmospheres on respiration, chip color, sugars and malate of stored potatoes. J. Amer. Soc. Hort. Sci. 108(1):129–133.
14. Smock, R.M. and G.D. Blanpied. 1963. Some effects of temperature and rate of oxygen reduction on the quality of controlled atmosphere stored 'McIntosh' apples. Proc. Amer. Soc. Hort. Sci. 83:135–138.
15. Sommer, N.F., R.J. Fortlage, and D.C. Edwards. 1983. Minimizing postharvest diseases of kiwifruits. Calif. Agr. 37(1&2):16–18.