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Effects of 2% O_2 and Varying Concentrations of CO_2 with or without C_2H_4 on the Storage Performance of Kiwifruit

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Abstract. **The storage performance of kiwifruit (*Actinidia chinensis* Planch. 'Hayward') was evaluated during and after storage for up to 24 weeks in 2% O_2 and 0%, 3%, 5%, and 7% CO_2 at 0°C. In addition, the influence of exposure to 0.5 or 1 $\mu l \cdot liter^{-1}$ C_2H_4 on fruit performance was evaluated. The rate of softening during storage was reduced in proportion to the CO_2 level and was accelerated by C_2H_4. The presence of white core inclusions under controlled atmospheres (CA) plus C_2H_4 was dependent upon the CO_2 concentration. Two other physiological disorders were observed, and their severity was influenced by the combination of elevated CO_2 and C_2H_4. The results suggest that there are 2 types of interactions between CO_2 and C_2H_4, competition and synergism, which occur in kiwifruit during storage.**

CA storage has been shown both experimentally and commercially to extend the shelf life of many horticultural commodities (7, 16). In recent years CA storage of kiwifruit has been successful because it alleviates the softening problem which occurs during storage in air at 0°C (1, 12, 13). For maximum benefit, CA storage of kiwifruit must be established within one week of harvest (2).

Successful CA storage depends upon a number of factors, particularly the levels of CO_2 and C_2H_4 in the storage atmosphere (7, 16). Although Blanpied et al. (4) initially reported that C_2H_4 had no effect during CA storage of apples , Liu (11) subsequently showed that C_2H_4 influenced the rate of softening and loss of acidity. We reported the detrimental effects of C_2H_4 during CA storage of kiwifruit (1). McDonald and Harman (12) confirmed that the benefit of CA is minimized if C_2H_4 is present.

This study was designed to examine the effects of CO_2 at 0%, 3%, 5%, and 7% in conjunction with 2% O_2 on the storage performance of kiwifruit, and also to evaluate the influence of 0.5 or 1.0 $\mu l \cdot liter^{-1}$ C_2H_4 when combined with the various CA treatments.

Materials and Methods

Kiwifruit 'Hayward' were harvested during the 1980 and 1982 seasons from the same commercial planting in Gridley, Calif., and transported to the Postharvest Pomology Research Facility at the Univ. of California, Davis. To minimize decay during storage, 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, adjusted to pH 11.0 (17). The fruit were sorted to eliminate defective or blemished individuals and then cooled overnight at 0°C.

After cooling, fruit either were placed in vented polyethylene bags for air storage in a room with low (<0.015 $\mu l \cdot liter^{-1}$) C_2H_4 contamination in the air or in 1.5 m^3 CA storage chambers. The desired CA treatment was attained within 24 hr of harvest by a flow-through system (500 $ml \cdot min^{-1}$). Storage atmospheres were monitored by gas chromatography and maintained within 5% of the desired level. The 1980–1981 storage test consisted of 4 CA treatments (air, 2% O_2, air + 5% CO_2, and 2% O_2 + 5% CO_2) with or without the addition of 1.0 $\mu l \cdot liter^{-1}$ C_2H_4. Five CA treatments (air, 2% O_2, 2% O_2 +

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3% CO_2, 2% O_2 + 5% CO_2, and 2% O_2 + 7% CO_2) with or without the addition of 0.5 $\mu l \cdot liter^{-1}$ C_2H_4 were used in the 1982–1983 storage test.

At periodic intervals (8, 12, and 24 weeks in 1980–1981 and 2, 4, 6, 8, 12, 16, 20, and 24 weeks in 1982–1983), fruit were removed from storage, warmed to 20°C and evaluated within 2 hr. Fifteen (1980) or 25 (1982) fruit were evaluated for flesh firmness and visual quality. Titratable acidity (TA) and soluble solids content (SSC) also were measured during the 1982 season. During both years, additional fruit were transferred to air at 20° and 95% RH for 7 days, then firmness (15 fruit) and visual quality (25 fruit) again were evaluated. SSC and TA were measured after 7 days at 20° following 12 and 24 weeks of 0° storage during 1982.

Two firmness measurements were taken for each pared fruit using a UC Fruit Firmness Tester with an 8 mm-tip (6); individual fruit were considered as replicates for statistical analyses. Lengthwise wedges of tissue from each fruit were juiced collectively for SSC and TA determinations. An American Optical Refractometer with automatic temperature compensation was used to measure SSC. TA was determined by titrating 6.0 g juice with 0.1 N NaOH to pH 8.2 and expressed as percentage citric acid. Visual quality of the fruit was evaluated by cutting the fruit lengthwise exposing both the pericarp and core tissue. All fruit were examined for the occurrence of white inclusions in the core tissue (Fig. 1A). The following scoring system was used to rate severity of the disorder: 0 = none; 1 = slight; 2 = moderate; and 3 = severe. In addition, any other signs of tissue breakdown were noted. During the 1982 storage tests, fruit held under various storage treatments also developed translucent (Fig. 1B) and/or granulated (Fig. 1C) patches in the outer pericarp tissue. The severity and percentage of the fruit exhibiting these symptoms were also recorded using a similar scoring system to that used for the occurrence of the white core inclusions.

Results and Discussion

The occurrence of white core inclusion (Fig. 1A) appeared to be a result of an interaction between CO_2 and C_2H_4, and the tendency to develop white core inclusions had been determined during the 1st 8 weeks of storage (Table 1). Flesh softening occurred in all treatments but was the least when fruit were kept in 2% O_2 + 5% CO_2. The presence of C_2H_4 accelerated the softening process in all treatments.

The benefits of CA for the storage of kiwifruit have been reported elsewhere (1, 2, 12, 13). Mitchell et al. (13) reported consistent beneficial results from the use of 2% O_2 + 5% CO_2. McDonald and Harman (12) observed a retardation in softening

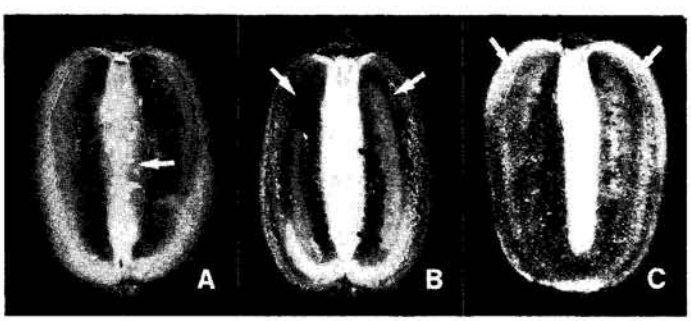

Fig. 1. Symptoms of white core inclusions **(A)**, translucency **(B)**, and graininess **(C)** in the kiwifruit.

Table 1. Percentage of incidence[z] of white core inclusions after 8 or 24 weeks of 0°C storage during the 1980–1981 season.

Storage atmosphere			Incidence (%)	
O_2 (%)	CO_2 (%)	C_2H_4 ($\mu l \cdot liter^{-1}$)	8 weeks	24 weeks
Air	---	0	0 b[y]	0 c
Air	---	1	0 b	0 c
2	0	0	0 b	0 c
2	0	1	0 b	0 c
Air	5	0	0 b	0 c
Air	5	1	87 a	100 a
2	5	0	0 b	0 c
2	5	1	93 a	87 b

[z]Percentage of fruit affected after indicated storage period plus 7 days in air at 20°C. Evaluations made on 15 fruit (2% O_2 and 5% CO_2) or 25 fruit (air and 2% O_2 + 5% CO_2).

[y]Mean separation in columns by LSD, 1% level.

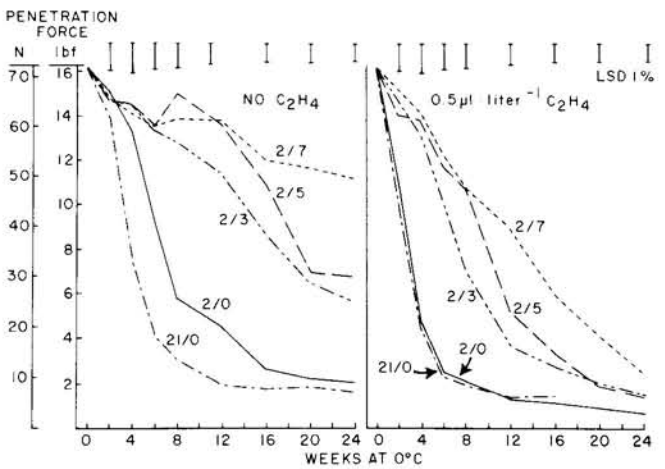

Fig. 2. Kiwifruit softening during storage at 0°C in either air (21/0) or indicated CA (% O_2/% CO_2) combinations with or without the addition of 0.5 $\mu l \cdot liter^{-1}$ C_2H_4. LSD values shown were calculated based on a one-way analysis of variance.

when CO_2 concentration (with 15% to 20% O_2) exceeded 4% but attained the best results when the O_2 concentration was reduced to 2% to 3%.

Our data corroborated previous observations (12, 13) that CO_2 concentration has a greater influence than O_2 concentration in retarding flesh softening of kiwifruit during storage (Fig. 2). Although 2% O_2 without CO_2 initially slowed fruit softening rate as compared to the air control, this difference was not significant after the 16th week of storage. The presence of high concentrations of CO_2 seemed to be essential in maintaining the firmness of the fruit during long-term CA storage. The extent of softening in all instances was dependent upon the concentration of CO_2 in the atmosphere and the presence or absence of C_2H_4. A 2-way analysis of variance showed that there was a highly significant interaction (P = 0.001) between the CO_2 concentration and the presence or absence of C_2H_4 in matched treatments. The addition of C_2H_4 to the atmosphere resulted in an acceleration of softening after 6 weeks in storage (Fig. 2).

The general pattern of changes in SSC and TA was not influenced greatly by storage treatment (Fig. 3). Fruit kept in 3%, 5%, or 7% CO_2 + 2% O_2 without C_2H_4 had a higher TA upon removal from storage than those kept in 2% O_2 or air. This

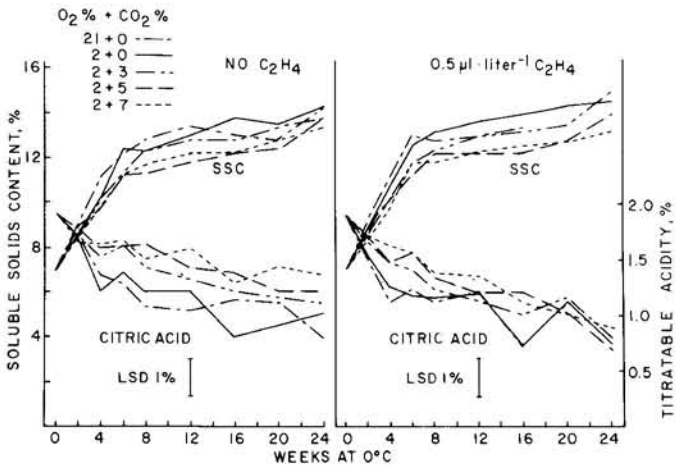

Fig. 3. Titratable acidity (% citric acid) and soluble solids content (SSC) changes in kiwifruit stored at 0°C in either air (21/0) or indicated CA (% O_2/% CO_2) combinations with or without the addition of 0.5 µl·liter^{-1} C_2H_4.

difference disappeared after the fruit were held in air at 20°C for 7 days (data not presented).

White core inclusions were observed only in the 2% O_2 treatments with 3%, 5%, and 7% CO_2 + 0.5 µl·liter^{-1} C_2H_4 (Fig. 4). They were 1st observed after 4 weeks in storage, before significant flesh softening differences had developed among fruit kept in comparable CA conditions without C_2H_4 (Fig. 2). The occurrence and severity of white core inclusions were related to CO_2 concentration. The severity of this disorder during the 1982 storage season was less than previously observed (1), perhaps due to seasonal variability. Seasonal variation in fruit susceptibility to physiological disorders has been reported previously for 'McIntosh' apples (16) and 'Bosc' pears (3).

During the 1982 storage tests, internal breakdown of fruit was 1st noted after ripening of the fruit following 12 weeks of storage. The severity of the breakdown increased with longer storage durations (data not presented). Two types of flesh breakdown were observed. In one, translucent patches developed in the outer pericarp tisue at the fruit's stylar end just below the epidermis (Fig. 1B). In some fruit, the translucent patches extended up the sides of the fruit. Granular texture of the outer pericarp tissue (Fig. 1C) characterized the other type of breakdown. The occurrence of granulation (graininess) occurred predominately in the stylar end. There was no obvious correlation between the 2 types of breakdown, since the symptoms could occur independently.

The presence of C_2H_4 (0.5 µl·liter^{-1}) during CA storage influenced the severity of both types of fruit breakdown (Table 2). Fruit kept under 3%, 5%, or 7% CO_2 with C_2H_4 generally showed more severe 'graininess' than fruit stored without C_2H_4. The regression coefficient of CA + C_2H_4 treatments with incidence of graininess was 0.91. Fruit stored in air did not differ from CA-stored fruit in graininess scores. Fruit breakdown which resulted in tissue translucency showed a different relationship between severity and storage treatment. Without C_2H_4, CA storage resulted in fruit with significantly less severe translucency than fruit stored in air (the regression coefficient of CA treatments with translucency was −0.79); however, the presence of C_2H_4 negated this benefit (the regression coefficient of CA + C_2H_4 treatments with translucency was not significant).

Our results indicate that there may be 2 types of CO_2/C_2H_4 interactions occurring during the storage of kiwifruit. One is a

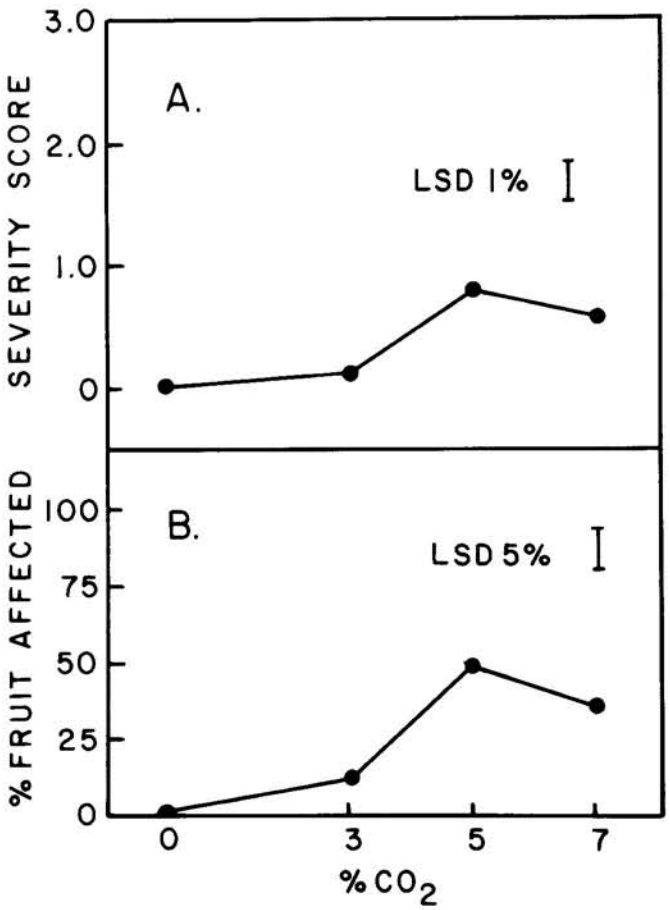

Fig. 4. Cumulative white core inclusion severity and occurrence during 24 weeks of 0°C storage in 2% O_2 in combination with 0%, 3%,5%, or 7% CO_2 plus the addition of 0.5 µl·liter^{-1} C_2H_4. Fruit evaluations were made after 2, 4, 6, 8, 12, 16, 20 and 24 weeks at 0°C plus 7 days in air at 20°. **A.** Severity score for core inclusions: 0 = none; 1 = slight; 2 = moderate; and 3 = severe. **B.** Percentage of fruit in each treatment showing core inclusions.

Table 2. Internal breakdown in kiwifruit after 24 weeks 0°C storage plus 7 days in air at 20° during the 1982–1983 season.

Storage atmosphere		C_2H_4 (µl·liter^{-1})			
		Graininess (% fruit affected)		Translucency (% fruit affected)	
O_2 (%)	CO_2 (%)	0	0.5	0	0.5
Air	---	68	---	83	---
2	0	52	60	36	92
2	3	48	74	4	61
2	5	50	76	10	96
2	7	65	100	0	80

competitive interaction which influences flesh softening. When C_2H_4 was present in the storage atmosphere, increases in CO_2 concentration reduced the rate of flesh softening. The competitive interaction between CO_2 and C_2H_4 was documented 1st by Burg and Burg (5). Since then, CO_2/C_2H_4 effects have been reported for a number of horticultural commodities. For example, Klaustermeyer et al. (9) reported that the incidence of C_2H_4-induced russet spotting in lettuce decreased with storage in low O_2 and/or high CO_2 atmospheres. Lipe and Morgan (10)

reported that CO_2 inhibited dehiscence in detached fruit, but exposure to C_2H_4 overcame this inhibition.

The occurrence of white core inclusions indicated a synergistic interaction between CO_2 and C_2H_4. In our storage tests, the development of the white core inclusion disorder preceded the period of accelerated flesh softening and was concomitant with the initial rapid increase in SSC. The primary source of the increase in SSC in the kiwifruit seems to be from the conversion of starch to soluble sugars. When fruit with white core inclusions were stained with iodine-potassium iodide solution, areas of the core tissues which were affected exhibited a positive reaction for starch. These observations suggested that starch metabolism was disrupted by a combined effect of CO_2 + C_2H_4 in localized areas of the core tissue subsequently appearing as white inclusions.

Synergistic effects between CO_2 and C_2H_4 have been reported. Kader et al. (8) reported that rusty-brown discoloration of lettuce increased in severity in the presence of CO_2 and C_2H_4. In a study on lettuce seed thermodormancy, Negm et al. (14) reported that both CO_2 and C_2H_4 were necessary to overcome thermodormancy. The action of C_2H_4, however, appeared to be dependent upon the CO_2 concentration. Scott and Wills (15) reported that the primary cause of brown heart in pears is due to CO_2 but the incidence was influenced by the presence of C_2H_4.

Although it would appear from the data presented on flesh firmness that a combination of 2% O_2 + 7% CO_2 would be the most beneficial atmosphere, it was been reported (13; J.E. Harman, personal communication) that kiwifruit can be injured by CO_2 levels of 8% or higher. Although a formal taste panel was not conducted in our tests, in routine taste evaluations made during the course of the study, fruit which had been stored in 2% O_2 + 7% CO_2 at 0°C and subsequently ripened in air at 20° developed a slight off-flavor. These observations suggest that kiwifruit have the longest storage life at O°, when the atmosphere contains 2% O_2 + 5% CO_2 and when C_2H_4 is exlcuded as completely as possible.

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