Monro, H.A.U. 1969. Manual of fumigation for insect control, 2nd ed. FAO Agr. Study 79. Rome, Italy.
Tebbets, J.S., P.L. Hartsell, H.D. Nelson, and J.C. Tebbets. 1983. Methyl bromide fumigation of tree fruits for control of the Mediterranean fruit fly: concentrations, sorption, and residues. J. Agr. Food Chem. 31:247–249.
USDA. 1979a. Plant protection and quarantine treatment manual, Sect. VI-T107 (rev. Jan. 1982). USDA, Animal and Plant Health Inspection Serv. p. 23.
USDA. 1979b. Plant protection and quarantine treatment manual, Sect. VI-T108 (rev. Jan. 1982). USDA, Animal and Plant Health Inspection Serv. p. 26.
Wells, J.M. and M.H. Gerdts. 1971. Pre- and postharvest benomyl treatments for control of brown rot of nectarines in California. Plant Dis. Rptr. 55(1):69–72.
Wells, J.M. and J.M. Harvey. 1970. Combination heat and 2,6,-dichloro-4-nitroaniline treatments for control of Rhizopus and brown rot of peaches, plums, and nectarines. Phytopathology 60(1):116–120.
Winchester, R.V. 1978. Determination of total bromide in cereals, nuts, and dried fruits by X-ray fluorescence spectroscopy. New Zealand J. Sci. 21:335–338.
Yokoyama, V.Y., G.T. Miller, and P.L. Hartsell. 1987. Methyl bromide fumigation for quarantine control of codling moth (Lepidoptera: Tortricidae) on nectarines. J. Econ. Entomol. 80:840–842.
Zerbe, G. 1978. On Fieller's theorem and the general linear model. Amer. Stat. 32:103–106.

J. AMER. SOC. HORT. SCI. 114(4):629–634. 1989.

Residual Effects of Controlled Atmospheres on Postharvest Physiology and Quality of Strawberries

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Abstract. **Low O_2 (2.0%, 1.0%, or 0.5%) or elevated CO_2 (10%, 15%, or 20%) concentrations and their combinations reduced respiration and ethylene production rates of 'Selva' strawberries (*Fragaria* ×*ananassa* Duch.) stored at 2C. After transfer from the various controlled atmospheres (CA) to air, respiration and ethylene production rates increased, but were still significantly lower than those of the fruits kept continuously in air. Atmospheres of 1.0% O_2 + 15% CO_2 and 0.5% O_2 + 20% CO_2 led to the accumulation of ethanol, which was still present at concentrations >100 $\mu l \cdot liter^{-1}$ (ppm) in strawberry juice after their transfer to air for several days. Keeping strawberries in CA had residual effects on maintaining their flesh firmness and color, but had no significant effects on skin or juice color, titratable acidity, pH, soluble solids content, and ascorbic acid content. In general, as O_2 concentration was decreased or as CO_2 concentration was increased, the residual effects were more pronounced. The combinations of reduced O_2 and elevated CO_2 had more pronounced residual effects than either reduced O_2 or elevated CO_2 alone. Exposures to CA for 4 days had greater residual effects than exposure to CA for 1 to 3 days.**

Controlled atmospheres with reduced O_2 and/or elevated CO_2 concentrations have been successfully used in extending the postharvest life and maintaining quality in strawberries. The effects of CA on postharvest physiology and quality attributes of strawberries include controlling postharvest decay (Couey et al., 1966; Couey and Wells, 1970; Sommer et al., 1973; El-Kazzaz et al., 1983; Harvey, 1982; Prasad and Stadelbacher, 1974; Shaw, 1969; Smith, 1957; Wells, 1970; Woodward and Topping, 1972), reducing rates of respiration (Siriphanich, 1980; Tomalin and Robinson, 1971; Woodward and Topping, 1972) and ethylene production (El-Kazzaz et al., 1983; Siriphanich, 1980), retarding softening (El-Kazzaz et al., 1983) and increasing accumulation of certain volatiles (Prasad and Stadelbacher, 1974; Shaw, 1969; Smith, 1957; Woodward and Topping, 1972).

Although the effects of CA storage on postharvest life of strawberries have been investigated, no work has been done to quantify the residual effects of CA on rate of strawberry deterioration after removal from CA to air. Such information can be used in managing the use of CA during transit and temporary storage of strawberries to maximize maintenance of their quality and reduction of postharvest losses.

The objectives of this research were to study the residual effects of exposure to various O_2 or CO_2 levels and their combinations for various durations on strawberries following transfer to air.

Materials and Methods

Fruit source and preparation. During the period from July to Oct. 1987, 'Selva' strawberries were obtained on the day of harvest from Naturipe Cooperative in Watsonville, Calif. After transport (3 hr in an air-conditioned car) to the laboratory, the strawberries were sorted to remove damaged, unripe, and overripe fruits. Then, ≈35 selected fruits were put in a 2-liter glass jar as one replicate; three replicates were used per treatment.

Treatments and storage conditions. The jars were then placed at 2C and ventilated with air or the desired gas mixtures at a continuous flow of about 25 $ml \cdot min^{-1}$, using flow boards and capillary tubing for flow control.

The first three tests dealt with the effects of the following groups of CA combinations on strawberries: Test 1: air, 2.0%, 1.0%, or 0.5% O_2; Test 2: air, or air + 10%, 15%, or 20% CO_2; Test 3: air, 2.0% O_2 + 10% CO_2, 1.0% O_2 + 15% CO_2, or 0.5% O_2 + 20% CO_2. The air control strawberries were stored for 14 days, while all CA-treated fruits were stored in CA conditions for 7 days and then transferred to air for another 7 days. In the second group of three tests, the strawberries were stored in air for 8 days or in 0.5% O_2 (Test 4); 20% CO_2 (Test 5); or 0.5% O_2 + 20% CO_2 (Test 6) for 1, 2, 3, or 4 days; followed by holding in air for 7, 6, 5, or 4 days, respectively.

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Gas mixing and analysis. The desired CA combinations were obtained by mixing air, N, and/or CO_2 in various volume ratios. The compositions of all gas mixtures were verified each day by taking a 10-ml gas sample and analyzing it by a Carle gas chromatograph equipped with a thermal conductivity detector.

Measurements of respiration and ethylene production rates. A 10-ml gas sample was taken from each jar. Carbon dioxide production rates of fruits kept under reduced O_2 atmospheres or air were based on analyses of concentration measured with a Horiba infrared CO_2 gas analyzer (Model SX-2), O_2 consumption rates of fruits stored in CO_2-enriched atmospheres on measurements made with an electrochemical S-3A oxygen analyzer, and ethylene production rates on those made with a Carle gas chromatograph equipped with a flame ionization detector.

Determination of volatile compounds. Frozen juice of strawberries was thawed and then centrifuged at 25,000× *g* for 20 min. at 0C. One milliliter supernatant was diluted with 10 ml of double-deionized water and filtered through a 0.45-μm microfilter in a 0C room. The filtrate was used for determining the concentrations of ethanol, methanol, and acetaldehyde by a HP5890A gas chromatograph with a flame ionization detector, the oven at 85C and the detector at 250C.

Measurements of firmness and color. Flesh firmness was measured as penetration force with a U.C. Fruit Firmness Tester, using a 3.2-mm plunger tip. A round area 2 cm in diameter was peeled at both sides of a fruit and measurements were made on the peeled areas. Skin, flesh, and juice colors were measured by a Gardner XL-23 Tristimulus Colorimeter, using the 'a' value. Positive and negative 'a' values indicate red and green color, respectively.

Determination of titratable acidity, pH, and soluble solids content. An automatic tritrator was used to determine pH and titratable acidity. Fresh juice (4 g) was diluted with 20 ml deionized water, its pH was measured, then it was titrated with 0.1 N NaOH. Titratable acidity was calculated as percent citric acid. Undiluted fresh juice was used to measure soluble solids content (SSC) by an Abbé Refractometer.

Determination of ascorbic acid. Frozen strawberries were thawed and 50 g of tissue was taken from eight fruit and sliced. The tissue was blended by a Polytron blender in 100 ml of 0.1% (w/v) oxalic acid solution. The homogenate was filtered through four layers of cheesecloth and centrifuged for 20 min at 25,000× *g* at 0C. One milliliter of supernatant was diluted with 9 ml of 0.1% oxalic acid solution and filtered through a 0.45-μm microfilter. The filtrate was used to determine ascorbic acid content. A Bio-Rad high-performance liquid chromatograph system with an ion exclusion HPX-87H column and a Bio-Rad UV Monitor (Model 1306) at 245 nm wavelength was used for the analysis at 20C. Mobile phase was 0.01 N H_2SO_4 and flow rate was 0.8 ml·min^{-1}.

Statistical analysis was done using analysis of variance for each test and, when differences were significant, LSD test was used for mean separation.

Results and Discussion

Effects of exposure to various O_2 and CO_2 levels and their combinations on strawberries.

Respiration. Strawberries kept in 0.5 to 2% O_2 had lower respiration rates, based on CO_2 evolution, than those held in air (Fig. 1A). Upon transfer to air, respiration rates increased gradually but remained lower than those of the fruits continuously stored in air. The 0.5% O_2 atmosphere was more effective in reducing respiration rates, and its residual effect was greater than those with 1.0% and 2.0% O_2. There was no significant difference between 1.0% and 2.0% O_2 in reducing respiration rates.

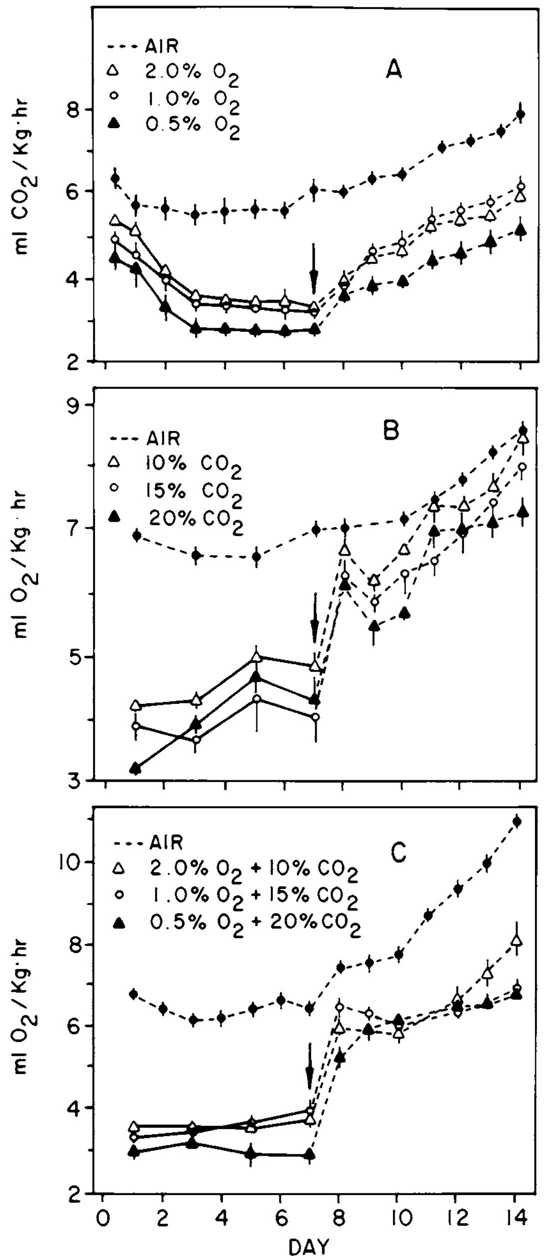

Fig. 1. Effects of exposure at 2C to various levels of O_2 (**A**), CO_2 (**B**), or their combinations (**C**) for 7 days followed by 7 days in air at 2C on respiration rate of 'Selva' strawberries. Bars on data points represent SDs; arrows indicate date of transfer to air.

The respiration rates of the strawberries held in CO_2-enriched atmospheres, as determined by O_2 uptake, were lower than those of the fruits kept in air (Fig. 1B). Generally, 20% and 15% CO_2 were more effective than 10% CO_2 in lowering respiration rate. When the fruits were transferred to air, their respiration rates increased, but were still lower than those of the strawberries continuously stored in air.

CA combinations of reduced O_2 and elevated CO_2 lowered respiration rates, based on O_2 consumption, of strawberries (Fig. 1C); 0.5% O_2 + 20% CO_2 was the most effective. There was no significant difference in respiration rates between strawberries kept in 2.0% O_2 + 10% CO_2 and those stored under 1.0% O_2 + 15% CO_2. When the fruits were transferred to air, respiration rates increased, but were still lower than those of the strawberries continuously exposed to air.

As measured after 7 days storage in CA, reduced O_2 was ≈10% more effective than elevated CO_2 in lowering respiration rates, and the combinations of reduced O_2 and elevated CO_2 were no more effective than reduced O_2 alone (38% to 55% vs. 45% to 54%, respectively). After storage in air for another 7 days (day 14), the reduction of respiration rates of the strawberries previously stored in reduced-O_2 atmospheres was greater than that in the fruits previously treated with elevated CO_2 (21% to 35% vs. 2% to 15%, respectively). The residual effects of the combinations were comparable to those of reduced O_2 alone, except the 1.0% O_2 + 15% CO_2, which had a greater effect than that of either 1.0% O_2 or 15% CO_2 alone (36% vs. 21% vs. 7% reduction, respectively).

Ethylene production. Ethylene production rates of strawberries stored in 2.0%, 1.0%, or 0.5% O_2 were greatly reduced as compared to the air control (Fig. 2A); 0.5% O_2 was more effective than 1.0% and 2.0% O_2. When transferred to air, C_2H_4 production rates increased, but remained lower than C_2H_4 production by fruits kept continuously in air for 14 days.

When strawberries were stored in air + 10%, 15%, or 20% CO_2, C_2H_4 production rates were reduced in proportion to the increase in CO_2 concentration (Fig. 2B). Upon transfer of the strawberries from elevated CO_2 atmospheres to air, C_2H_4 production rates gradually increased, but remained lower than those of the control fruits; 15% and 20% CO_2 had more pronounced residual effect than 10% CO_2.

The strawberries stored in CA combinations of reduced O_2 and elevated CO_2 had lower C_2H_4 production rates than the fruits stored in air (Fig. 2C). Siriphanich (1980) and El-Kazzaz et al. (1983) reported similar effects of CA on reducing C_2H_4 production by strawberries. There was no significant difference among these CA treatments. After the CA-treated fruits were transferred to air, C_2H_4 production rates increased, but were still lower than those of fruits kept continuously in air. The residual effects of reducing C_2H_4 production rates were especially noteworthy for the 0.5% O_2 + 20% CO_2 and 1.0% O_2 + 15% CO_2 treatments.

As measured after 7 days of storage in CA, reduced O_2 was more effective in lowering C_2H_4 production rates than elevated CO_2, and the combinations of both were more effective than either alone (63% to 70% vs. 42% to 58% vs. 67% to 75% reduction, respectively). Similar synergistic effects were noted after the fruits had been transferred to air for 7 days (day 14); the percent reductions were 16% to 40% vs. 24% to 48% vs. 43% to 73%, respectively.

Accumulation of volatile compounds. Strawberries stored with 1.0% or 0.5% O_2 for 7 days contained more ethanol than the air control fruits (Table 1). However, after the fruits had been held in air for another 7 days, the differences in ethanol content among these three treatments were very small. Low O_2 atmospheres had no effect on methanol or acetaldehyde concentrations, which ranged from 20 to 60 and from 80 to 100 μl·liter^{-1} juice, respectively (data not shown).

The fruits treated with 15% or 20% CO_2 had higher ethanol concentration than air control fruits (Table 1). After the high-CO_2-treated fruits had been held in air for 7 days, ethanol concentration declined in all treatments except the air control. In both tests, control strawberries continued to accumulate ethanol, but the concentration range after 14 days at 2C was still between 30 and 60 μl·liter^{-1} juice, which is not likely to have a negative effect on flavor.

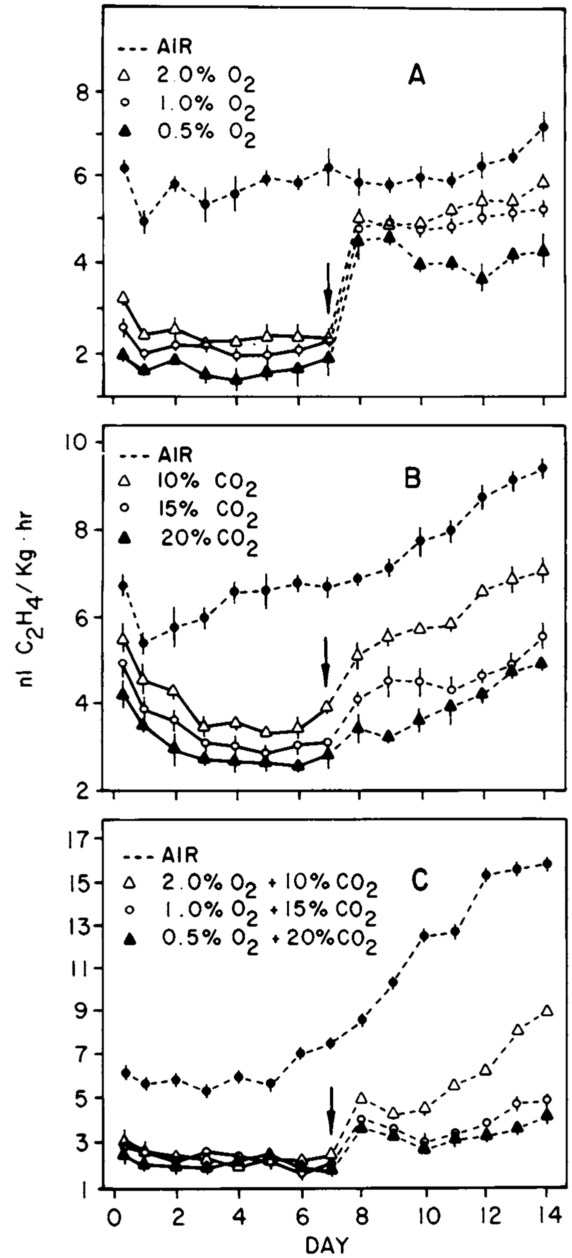

Fig. 2. Effects of exposure at 2C to various levels of O_2 (**A**), CO_2 (**B**), or their combinations (**C**) for 7 days followed by 7 days in air at 2C on ethylene production rate of 'Selva' strawberries. Bars on data points represent SDs; arrows indicate date of transfer to air.

The combinations of reduced O_2 and elevated CO_2 levels dramatically increased ethanol accumulation, especially for 0.5% O_2 + 20% CO_2 and 1.0% O_2 + 15% CO_2 (Table 1). These treatments also had increased acetaldehyde concentration by ≈50% and 20% on days 7 and 14, respectively, but had no effect on methanol content (data not shown). After the fruits had been transferred to air for 7 days (day 14), ethanol content of strawberries previously exposed to 1% O_2 + 15% or 0.5% O_2 + 20% CO_2 declined, but still was much higher than that of strawberries previously kept in 2% O_2 + 10% CO_2 or in air. Although only small residual effects on ethanol concentrations were observed with either reduced O_2 or elevated CO_2 alone, the combinations of 1% O_2 + 15% CO_2 and 0.5% O_2 + 20%

Table 1. Effects of exposure at 2C with various O_2 or CO_2 levels, or their combinations for 7 days followed by 7 days in air at 2C on ethanol content, flesh color, and firmness of 'Selva' strawberries.

Treatment (7 days) before holding in air for 7 days	Ethanol concn[z] (µl·liter⁻¹) Day 7	Day 14	Firmness on day 14 (N)	Color on day 14 (CDM[y] 'a' value)
Air	10.0	55.0	2.5	54.6
2.0% O_2	13.2	28.6	2.5	57.5
1.0% O_2	35.2	66.0	2.6	54.8
0.5% O_2	63.8	72.6	2.8	53.4
LSD at 5%	15.0	21.4	0.1	2.8
Air	18.9	42.8	2.5	55.4
Air + 10% CO_2	19.8	17.6	2.8	52.9
Air + 15% CO_2	40.5	19.8	2.7	52.8
Air + 20% CO_2	97.3	39.6	3.0	53.1
LSD at 5%	15.9	16.1	0.2	1.9
Air	28.6	30.8	2.6	53.7
2.0% O_2 + 10% CO_2	54.3	55.0	2.7	49.9
1.0% O_2 + 15% CO_2	270.6	143.0	3.3	48.0
0.5% O_2 + 20% CO_2	292.6	178.2	3.2	47.0
LSD at 5%	20.2	22.8	0.1	3.5

[z]Initial concentration was 9.2 ± 1.2 µl·liter⁻¹.
[y]CDM = Color Difference Meter.

CO_2 resulted in a pronounced residual effect. On day 14, ethanol concentrations in strawberries exposed to these treatments were three to four times greater than the control fruits. The higher concentrations of ethanol and acetaldehyde (100 to 200 µl·liter⁻¹) may cause off-flavors in these strawberries.

Quality attributes. Some residual effects of CA treatments were observed with flesh firmness and flesh color (Table 1). As measured on day 14, the fruits previously kept in 0.5% O_2 were slightly firmer than those continuously exposed to air or 2.0% or 1.0% O_2. The fruits previously treated with elevated CO_2 were all firmer than those continuously exposed to air; 20% CO_2 was the most effective. The combinations of reduced O_2 and elevated CO_2 also resulted in better firmness retention, which may delay incidence of decay (El-Kazzaz et al., 1983).

Reduced O_2 (0.5% and 1%) did not influence and the 2% O_2 slightly influenced the development of redness in the flesh of strawberries (Table 1). Elevated CO_2 slightly retarded color development, but no differences were noted among the three CO_2 concentrations tested. The combinations of reduced O_2 and elevated CO_2 retarded color development (relative to their control) to a slightly greater extent than elevated CO_2 alone (relative to their control).

None of the CA combinations tested had a significant effect on skin or juice color, titratable acidity, pH, soluble solids content, and ascorbic acid content of strawberries (data not shown).

Effects of exposure to 0.5% O_2, 20% CO_2, or 0.5% O_2 + 20% CO_2 for various durations

Since 0.5% O_2, 20% CO_2, and 0.5% O_2 + 20% CO_2 were generally the most effective treatments among the various CA combinations tested, these three treatments were selected to study the residual effects of exposure to CA for various durations.

Respiration. Strawberries kept in 0.5% O_2 had lower respiration rates than those stored in air (Fig. 3A). When transferred to air following storage in 0.5% O_2 for 1 to 4 days, respiration rates increased, but were still lower than those of the fruits continuously exposed to air, indicating the increasing residual effect of 0.5% O_2, which increased (from 7% to 21% reduction on day 8) with exposure time.

The fruits stored in 20% CO_2 had lower respiration rates than strawberries kept in air (Fig. 3B). Respiration rates of fruits that had been stored in 20% CO_2 for 1 to 4 days before transfer to air increased during the first day and then leveled off, but were still lower than those of fruits continuously stored in air. The residual effect of 4 days of exposure to 20% CO_2 was greater than those of shorter exposures (35% vs. 24% to 29% reduction on day 8).

Strawberries kept in 0.5% O_2 + 20% CO_2 had lower respiration rates than strawberries stored in air (Fig. 3C). Upon transfer to air, respiration rates rapidly increased during the first day and then leveled off, but remained lower than those of the fruits continuously stored in air. As measured on day 8, the residual effects of air + 20% CO_2 and 0.5% O_2 + 20% CO_2 on respiration rates were comparable and generally greater than the effects of the 0.5% O_2 treatment (24% to 35% vs. 19% to 24% vs. 7% to 21% reduction, respectively).

Ethylene production. The fruits stored in 0.5% O_2 had much lower C_2H_4 production rates than those of the strawberries stored in air (Fig. 4A). Upon transfer of the 0.5% O_2-treated fruits to air, C_2H_4 production rates rapidly increased, but were still lower by 2% to 14% on day 8 than those of the fruits continuously kept in air.

Storage in air + 20% CO_2 reduced C_2H_4 production rates (Fig. 4B). When transferred to air, C_2H_4 production rates by the strawberries increased rapidly, but were still lower than those of the air control. The residual effect of 4 days of exposure to 20% CO_2 was much more pronounced than that of shorter exposure times (43% vs. 10% or lower reduction on day 8).

Treatment with 0.5% O_2 + 20% CO_2 significantly reduced C_2H_4 production rates of strawberries (Fig. 4C). Upon transfer to air, C_2H_4 production rates rapidly increased, but remained lower by 15% to 30% than those of the control fruits. The residual effect of 0.5% O_2 + 20% CO_2 increased with exposure time from 1 to 4 days (15%, 21%, 27%, and 30% reduction on

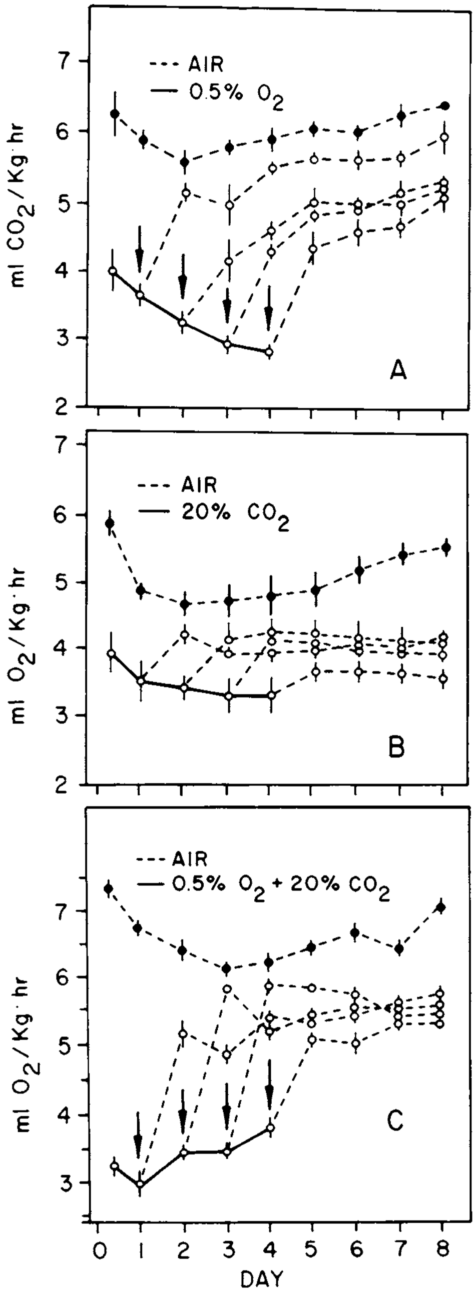

Fig. 3. Effects of exposure at 2C to 0.5% O_2 (**A**), 20% CO_2 (**B**), or 0.5% O_2 + 20% CO_2 (**C**) for 1, 2, 3, or 4 days and subsequent holding in air for 7, 6, 5, or 4 days at 2C on respiration rate of 'Selva' strawberries. Bars on data points represent SDs; arrows indicate times of transfer to air.

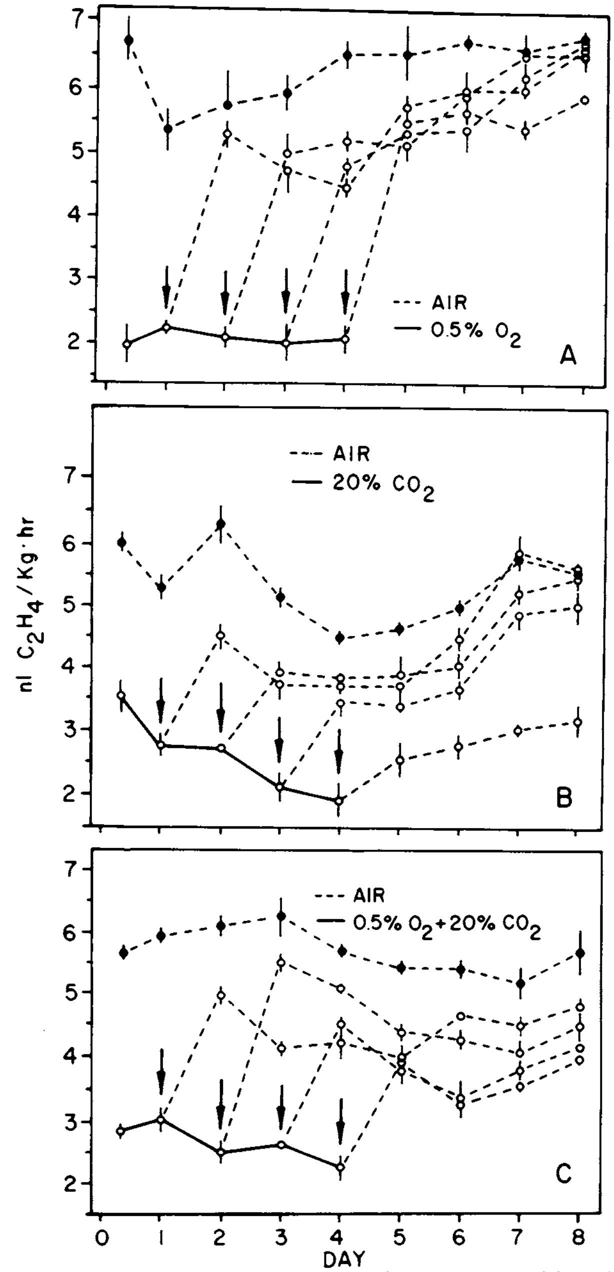

Fig. 4. Effects of exposure at 2C to 0.5% O_2 (**A**), 20% CO_2 (**B**), or 0.5% O_2 + 20% CO_2 (**C**) for 1, 2, 3, or 4 days and subsequent holding in air for 7, 6, 5, or 4 days at 2C on ethylene production rate of 'Selva' strawberries. Bars on data points represent SDs; arrows indicate times of transfer to air.

day 8, respectively). Treatment with 0.5% O_2 + 20% CO_2 for 1 to 3 days induced a larger residual effect than exposure to either 0.5% O_2 or 20% CO_2 alone (15% to 27% vs. 1% to 3% vs. 0% to 10% reduction on day 8, respectively), but 4 days of exposure did not show similar synergistic effects (14% vs. 43% vs. 30% reduction, respectively).

Accumulation of volatile compounds. The fruits stored in 0.5% O_2 or in 20% CO_2 had higher ethanol concentrations than the fruits stored in air, but, in all treatments, ethanol concentrations remained <30 $\mu l \cdot liter^{-1}$ (Table 2). The ethanol concentrations increased with exposure time. On day 8, no differences were observed in ethanol concentration among the 0.5% O_2 treatments. Ethanol content on day 8 was greater in the air control fruits than in the 20% CO_2-treated fruits.

Exposure to 0.5% O_2 + 20% CO_2 dramatically increased ethanol accumulation; the magnitude of this effect increased with exposure time. Ethanol concentration in the fruits treated with 0.5% O_2 + 20% CO_2 was much higher than that in the strawberries treated with either 0.5% O_2 or 20% CO_2 alone (Table 2). However, after transfer to air, ethanol concentration declined and differences among treatments on day 8 were small. This pattern was also true for methanol and acetaldehyde concentrations (range from 20 to 30 and 100 to 120 $\mu l \cdot liter^{-1}$, respectively). Such acetaldehyde concentrations are not likely to have any effects on flavor quality of strawberries (Shaw, 1969; Prasad and Stadelbacher, 1974).

Quality attributes. The strawberries stored in 0.5% O_2, 20% CO_2, or 0.5% O_2 + 20% CO_2 for 1 to 4 days before storage

Table 2. Residual effects of exposure at 2C to 0.5% O_2, 20% CO_2, or 0.5% O_2 + 20% CO_2 for 1, 2, 3, or 4 days and subsequent holding in air at 2C for 7, 6, 5, or 4 days on ethanol content, flesh color, and firmness of 'Selva' strawberries as measured on day 8.

Treatment	Ethanol concn[z] ($\mu l \cdot liter^{-1}$) At transfer from CA	Day 8	Firmness (N)	Color (CDM[y] 'a' value)
8 d in air	---	16.5	2.7	55.2
1 d (0.5% O_2) + 7 d (air)	7.8	13.2	2.9	52.8
2 d (0.5% O_2) + 6 d (air)	15.4	13.2	2.8	54.1
3 d (0.5% O_2) + 5 d (air)	20.9	19.1	3.1	52.1
4 d (0.5% O_2) + 4 d (air)	26.4	15.4	3.2	51.5
LSD at 5%	6.9	9.2	0.1	2.7
8 d in air	---	11.1	3.2	53.3
1 d (air + 20% CO_2) + 7 d (air)	2.0	1.2	3.5	53.4
2 d (air + 20% CO_2) + 6 d (air)	6.6	1.5	3.5	54.6
3 d (air + 20% CO_2) + 5 d (air)	8.8	4.4	3.8	53.8
4 d (air + 20% CO_2) + 4 d (air)	24.2	8.8	4.0	50.7
LSD at 5%	2.4	4.8	0.2	2.6
8 d in air	---	19.8	2.6	57.9
1 d (0.5% O_2 + 20% CO_2) + 7 d (air)	35.2	28.6	3.5	55.3
2 d (0.5% O_2 + 20% CO_2) + 6 d (air)	72.6	26.4	3.4	56.2
3 d (0.5% O_2 + 20% CO_2) + 5 d (air)	145.2	24.2	3.6	54.6
4 d (0.5% O_2 + 20% CO_2) + 4 d (air)	202.4	37.4	3.5	52.7
LSD at 5%	17.9	5.4	0.2	3.9

[z]Initial concentration was 2.3 ± 1.4 $\mu l \cdot liter^{-1}$ and increased to 3.4 ± 2.8, 4.9 ± 2.2, 5.7 ± 1.4, and 6.6 ± 2.3 $\mu l \cdot liter^{-1}$ after 1, 2, 3, and 4 days, respectively.
[y]CDM = Color Difference Meter.

in air for 4 to 7 days were firmer than the fruits continuously stored in air (Table 2). Exposure to 0.5% O_2 or 20% CO_2 for 3 or 4 days had greater residual effect on firmness retention than exposure for 1 or 2 days. The residual effect of 0.5% O_2 + 20% CO_2 on flesh firmness was more pronounced than that of either 0.5% O_2 or 20% CO_2 alone relative to the control in each case.

Exposure to 0.5% O_2, air + 20% CO_2, or 0.5% O_2 + 20% CO_2 for 4 days retarded reddening in strawberry flesh relative to the controls (Table 2). None of the CA treatments tested had any significant effects on skin or juice color, titratable acidity, pH, soluble solids content, and ascorbic acid content of strawberries (data not shown).

Results from this research demonstrate the residual effects of CA on postharvest physiology and quality of strawberries. These residual effects of CA may include the reduction of respiration and C_2H_4 production rates, accumulation of ethanol and possibly other volatiles, maintenance of flesh firmness, and retardation of flesh color development. Generally speaking, as the concentration of O_2 is decreased, the concentration of CO_2 is increased, and the duration of exposure to CA conditions is increased and the residual effects become more prominent. Some combinations of reduced O_2 and elevated CO_2 have synergistic residual effects. Exposure of strawberries to controlled or modified atmospheres containing 15% to 20% CO_2 and 1% to 2% O_2 for at least 3 days will help maintain their quality during transport and temporary storage and will slow deterioration during subsequent handling in air.

Literature Cited

Couey, H.M., M.N. Follstad, and M. Uota. 1966. Low oxygen atmospheres for control of postharvest decay of fresh strawberries. Phytopathology 56:1339–1341.

Couey, H.M. and J.M. Wells. 1970. Low oxygen or high carbon dioxide atmospheres to control postharvest decay of strawberries. Phytopathology 60:47–49.

El-Kazzaz, M.K., N.F. Sommer, and R.J. Fortlage. 1983. Effect of different atmospheres on postharvest decay and quality of fresh strawberries. Phytopathology 73:282–285.

Harvey, J.M. 1982. CO_2 atmospheres for truck shipment of strawberries, p. 359–366. In: D.G. Richardson and M. Meheriuk (eds.). Controlled atmospheres for storage and transport of perishable agricultural commodities. Ore. State Univ. Symp. Ser. I. Timber Press, Beaverton, Ore.

Prasad, M. and G.J. Stadelbacher. 1974. Effect of acetaldehyde vapor on postharvest decay and market quality of fresh strawberries. Phytopathology 64:948–951.

Shaw, G.W. 1969. The effect of controlled atmosphere storage on the quality and shelf life of fresh strawberries with special reference to *Botrytis cinerea* and *Rhizopus nigricans*. PhD Diss., Univ. of Maryland, College Park.

Siriphanich, J. 1980. Postharvest deterioration of strawberries as influenced by ethylene and some other volatiles. MS Thesis. Univ. of California, Davis.

Smith, W.H. 1957. The application of precooling and carbon dioxide treatment to the marketing of strawberries and raspberries. Scientia Hort. 12:147–153.

Sommer, N.F., R.J. Fortlage, F.G. Mitchell, and E.C. Maxie. 1973. Reduction of postharvest loss of strawberry fruits from grey mold. J. Amer. Soc. Hort. Sci. 98:285–288.

Tomalin, A.W. and J.E. Robinson. 1971. Refrigeration to store soft fruit. Grower 76:634–638.

Wells, J.W. 1970. Modified atmosphere, chemical and heat treatments to control postharvest decay of California strawberries. Plant Dis. Rptr. 54:431–434.

Woodward, J.R. and A.J. Topping. 1972. The influence of controlled atmospheres on the respiration rates and storage behavior of strawberry fruits. J. Hort. Sci. 47:547–553.