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Postharvest Quality and Storage Life of Grapes as Influenced by Adding Carbon Monoxide to Air or Controlled Atmospheres

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Abstract. **The effects of 10% carbon monoxide (CO) added to air or controlled atmospheres (2% O_2 with or without 5% CO_2) on quality and storage life of grapes (*Vitis vinifera* L. cv. Thompson Seedless) were compared with those of the conventional SO_2 fumigation treatments for decay control. CO in air reduced respiration and C_2H_4 production rates, and retarded berry browning and softening, but was only partially effective in retarding decay beyond 2 months at 0°C. SO_2 treatments were very effective in controlling the spread of decay, but brown discoloration of the berries increased, especially after 2 months at 0° or 1°. When combined with 2% O_2 with or without 5% CO_2, CO inhibited C_2H_4 production and retarded decay development, but the presence of CO_2 increased brown discoloration of the berries. A combination of 2% O_2 + 10% CO was as effective as SO_2 in controlling decay of grapes held at 0° for up to 4 months and caused less browning and bleaching than SO_2.**

SO_2, although effective in retarding the activity of decay-causing organisms in grapes, including *Botrytis cinerea* Pers., is very corrosive to metals, injurious to most other fresh fruits, and causes injury to grapes if used excessively (4, 5, 10, 11). The optimum SO_2 concentration used in grapes is usually a compromise between that which will provide acceptable control of decay and that which will not cause excessive injury (10).

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Controlled-atmosphere (CA) storage has been tested for decay control and extension of the storage life of grapes (13). Uota (16) showed that CA alone did not provide adequate decay control under conditions of relatively high humidity; however, combining CA (5% O_2 and 10% CO_2) with the application of 1000 ppm SO_2 at 7-day intervals gave almost complete decay control. Nassar (8) found that elevated CO_2 concentrations (up to 15%) increased browning of berries and resulted in the accumulation of α-amino butyric and succinic acids and reduction of aspartic and glutamic acids in grapes, but SO_2 fumigation did not change the organic and amino acids examined. Nelson (9) concluded that CA was not very promising for commercial grape storage, since grapes kept at less than 15% CO_2 had higher decay than those subjected to SO_2 fumigation; while 15% CO_2 controlled the decay, browning of the berries made it unsatisfactory. Harvey and Uota (5) also found that CA alone did not control decay of grapes unless the CO_2 levels were increased or the O_2 levels were reduced to the point where physiological disorders may occur.

CO is slightly fungistatic in air and often highly fungistatic in reduced O_2 (< 5%) atmospheres (1, 2, 3, 6, 7, 14, 15). Kader et al. (6) found that CO (5% and 10%) + 4% O_2 atmospheres retarded growth of *B. cinerea* on inoculated tomatoes harvested at the mature-green or pink stage and held at 12.5°C for up to 14 or 10 days, respectively. CO + CA inhibits decay caused by *B. cinerea* on cherries (14), strawberries (1, 3), apples (15), and kiwifruits (14). Peiser et al. (12) found that CO was not directly metabolized by lettuce leaf discs but was converted, in part, into CO_2 which was metabolized into organic acids and other constituents.

The goals of this study were to evaluate the possible use of CO alone or in combination with CA (2% O_2 with or without 5% CO_2) in suppressing decay and prolonging the storage life of 'Thompson Seedless' grapes and to compare these treatments with the use of SO_2 either by direct fumigation or through generators.

Materials and Methods

'Thompson Seedless' grapes were harvested from the Univ. vineyard at Davis, Calif. on August 20, 1981, and August 27, 1982 from vines that were girdled, thinned, and sprayed with 20 ppm gibberellic acid at full bloom and fruit set. Fruit clusters were sorted to eliminate defects and were matched into lots by color, size, and appearance. Three replicates (3 kg each) were used per treatment and for initial evaluation. Quality evaluations were made initially and then monthly during the storage period. They included overall appearance, decay incidence, browning of berries, and drying of stems using subjective scoring systems. Berry firmness was measured on 20 fruit per replicate using subjective scoring in 1981 and a UC Fruit Firmness Tester with a 4.8-mm plunger and berry skin removed in 1982. Soluble solids content (SSC) and pH were measured on juice samples. Titratable acidity (TA) was measured by titrating 10 ml juice to pH 8.1 with 0.133 N NaOH.

Grapes were kept in 2 controlled-temperature rooms, one for the CA treatments and the other for the SO_2 treatments to avoid SO_2 contamination in the first room. Fruit kept in air or CA at 0°C were placed in 10-liter, metal chambers that were ventilated with a continuous flow of the desired gas mixture. Control and SO_2-treated fruit were packed in shipping containers and placed on shelves at 1°.

The desired O_2, CO_2, and CO mixtures were provided by metering appropriate amounts of air, N_2, CO_2, and/or CO in a flow-through system using needle valves and capillary tubes as flow meters. Gas mixtures were verified and monitored every few days by analyzing them with a thermal conductivity gas chromatograph to ensure that the actual compositions were within 10% of the intended mixtures throughout the storage duration. Air and all gas mixtures were humidified by bubbling them through water before entering the CA chambers. The flow rates used were selected to ensure that CO_2 produced by the fruit did not accumulate above 0.4%. The CA treatments used in 1981 were: air control; air + 10% CO; 2% O_2 + 5% CO_2; and 2% O_2 + 5% CO_2 + 10% CO. CA treatments in 1982 were: air control; 2% O_2; and 2% O_2 + 10% CO.

SO_2 treatments in 1981 were: air control; conventional SO_2 fumigation treatment (SO_2/F); and in-package SO_2-generating pads (SO_2/G). Two 2-stage pads (4, 10) were used for each container (3 replicates of 3 kg each for a total of 9 kg of grapes) in the SO_2/G treatment. One pad was placed below and the 2nd on top of the packed fruit, and containers were wrapped in polyethylene film to restrict ventilation and to provide high humidity for the release of SO_2. For the SO_2/F, grapes were fumigated with 0.2% (v/v) SO_2 for 20 min in a fumigation chamber immediately after packing and subsequently with 0.1% SO_2 for 20 min at weekly intervals. In 1982, only the SO_2/G treatment was used and storage was at 0°C.

Respiration rate (CO_2 production) of grapes kept in air, 2% O_2 and 2% O_2 + 10% CO, and C_2H_4 production by fruits kept under all the CA treatments were measured every 2 or 3 days for 2 months, using gas chromatography.

After one month of storage in 1982, a taste panel, consisting of 6 trained judges, evaluated the sensory attributes of grapes from the 3 replicates of the 4 treatments using a simple triangle test. All possible combinations were used for each panelist in each replicate. The panelists subsequently were asked to score each sample for browning, bleaching, firmness, sulfury flavor, and off-flavor by marking 10-cm lines labeled near their ends by "none" and "extreme" on the score sheet. Judges were trained for 2 days before each monthly evaluation period. Consistent references of grapes exhibiting extreme browning, bleaching, or sulfury flavor were presented along with the samples and all evaluations (3 replicates) were made by the same judges to minimize variability. Judges received 4 samples of 20 fruit each per day (one session), in random order. Samples were presented to judges in individual booths under white lights. Judges were instructed to rinse their mouths with distilled water between samples and to expectorate samples.

Results and Discussion

CO added to air reduced CO_2 production by grapes; the effect was more pronounced during the 2nd month than during the first month of storage at 0°C (Fig. 1A). Both the 2% O_2 and the 2% O_2 + 10% CO atmospheres also reduced respiration rate during the 2nd month, but had no significant effect during the first month of storage (Fig. 1B). The 2- to 3-fold increase in CO_2 production rate by grapes kept in air may have been due to incidence and spread of decay.

CO effect on CO_2 production by fruits appears to be dependent upon their respiratory pattern. CO reduces CO_2 production by nonclimacteric fruits, as shown for grapes (Fig. 1A, B) and strawberries (3). On the other hand, CO stimulates CO_2 production by climacteric fruits, such as tomatoes (6) and peaches (7), perhaps due to its C_2H_4-mimicking characteristics and its stimulation of C_2H_4 production by these fruits.

Ethylene production rates by grapes were very low in all treatments (Fig. 2). Differences among treatments during the first month of storage were small and mostly not significant. During the 2nd month at 0°C, there was a 4- to 6-fold increase in C_2H_4 production by fruit kept in air (Fig. 2), which may have been due to spread of decay. All CA treatments, with or without CO, reduced C_2H_4 production rates, but CO-containing atmospheres enhanced the effect. The effectiveness of CO in reducing C_2H_4 production rates may have been largely due to its decay control effects, since it stimulates C_2H_4 production by other fruits (6, 7, 14).

The deterioration rate was fastest in grapes kept in air at either 0° or 1°C (Fig. 3). There were no significant differences among treatments other than the air control during the first month of storage. After 2 months, grapes kept under 2% O_2 + 5% CO_2 deteriorated to an overall appearance score below 5 (fair); thus, this treatment was discontinued along with the 2 air controls.

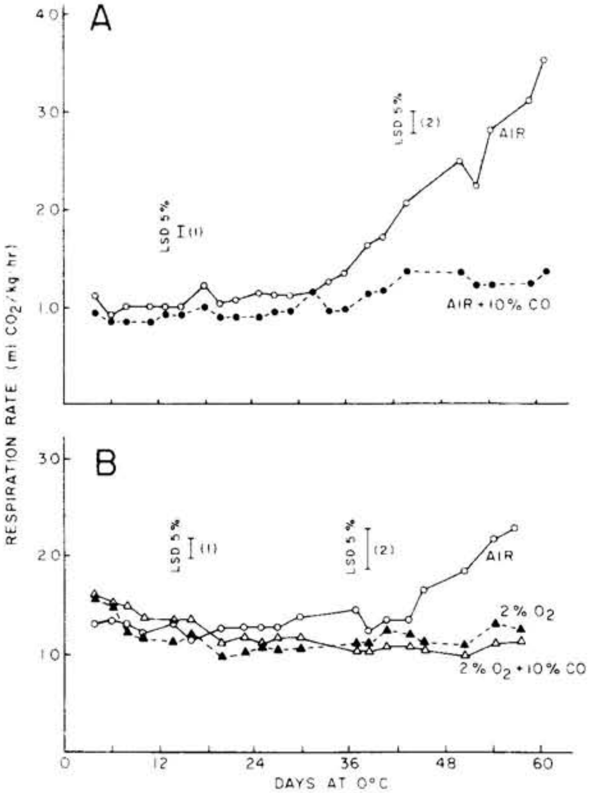

Fig. 1. Effects of CA treatments on respiration rates of 'Thompson Seedless' grapes during holding at 0°C for 60 days; A = 1981 study and B = 1982 study. LSD (1) and (2) are for the first and 2nd month of storage, respectively.

Decay was the main cause of deterioration in these and other treatments (Fig. 4). The effectiveness of CO added to air in controlling decay diminished following 2 months at 0° (Fig. 4). Although SO_2/F was very effective in preventing decay (Fig. 4), it did not differ from the air + CO treatment in overall appearance of grapes (Fig. 3) due to the pronounced browning caused by SO_2/F, especially during the 3rd and 4th months of storage (Table 1). The overall appearance of grapes held under CA + CO seemed slightly better than that of the SO_2/G-treated fruit after 3 and 4 months in storage, but the difference was not significant statistically (Fig. 3). By the end of 4 months, overall appearance scores of grapes stored under CA + CO were significantly better than those of fruits subjected to the SO_2/F or air + CO treatments. CO added to CA was markedly more effective than CO in air and was as effective as the 2 SO_2 treatments for decay control (Fig. 4). In the 1982 study, the 2% O_2 + 10% CO treatment was as effective as the SO_2/G for decay control for up to 4 months at 0° (Table 2). As has been noted with other fruits (1, 3, 6, 7, 14, 15), CO is more fungistatic when combined with reduced O_2 levels.

No significant differences in browning, pH, and TA and only small differences in firmness and SSC were noted among all

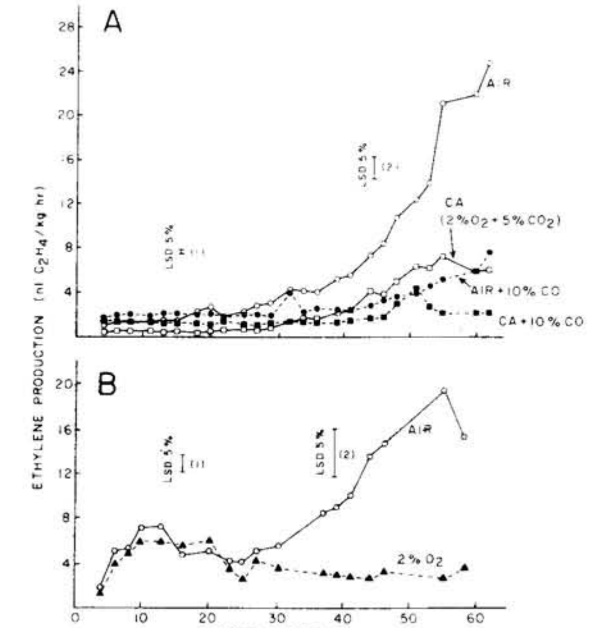

Fig. 2. Effects of CA treatments on ethylene production rates by 'Thompson Seedless' grapes kept at 0°C for 60 days; A = 1981 study and B = 1982 study. LSD (1) and (2) are for the first and 2nd month of storage, respectively.

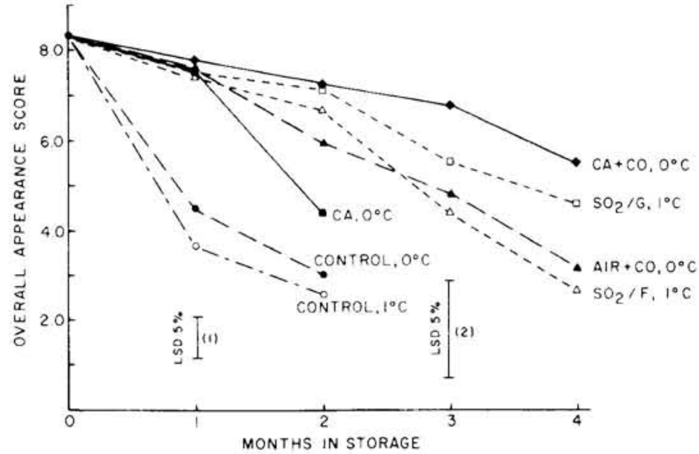

Fig. 3. Effects of storage conditions on the overall appearance quality (9 = excellent; 7 = good; 5 = fair; 3 = poor; 1 = very poor) of 'Thompson Seedless' grapes. LSD (1) is for the first 2 months and LSD (2) is for the last 2 months of storge (1981 study).

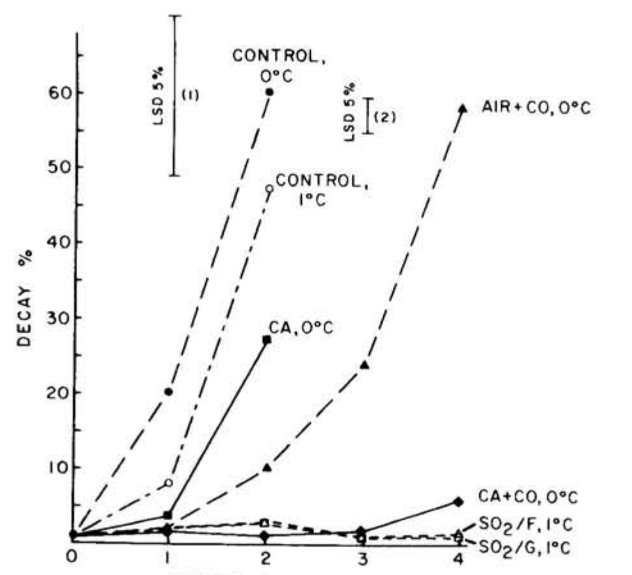

Fig. 4. Effects of storage conditions on decay incidence in 'Thompson Seedless' grapes. LSD (1) is for the first 2 months and LSD (2) is for the last 2 months of storage (1981 study).

Table 1. Effects of storage conditions on quality attributes of 'Thompson Seedless' grapes (1981 study).

Storage conditions							
Duration (months)	Temp (°C)	Treatment	Browning[z] (score)	Firmness[y] (score)	SSC (%)	pH	TA (% tartaric acid)
---	---	Initial	1.0	5.0	21.8	3.34	0.74
2	0	Air control	2.0 a[x]	3.5 b	21.1 ab	3.42 a	0.74 a
		Air + 10% CO	0.5 c	3.7 ab	20.2 bc	3.46 a	0.72 a
		CA(2% O_2 + 5% CO_2)	1.5 b	3.3 bc	19.6 c	3.43 a	0.73 a
		CA + 10% CO	1.3 b	4.0 a	21.6 a	3.50 a	0.70 a
	1	Air control	2.1 a	3.1 c	21.7 a	3.45 a	0.72 a
		SO_2/F	2.3 a	3.2 c	21.9 a	3.52 a	0.68 a
		SO_2/G	1.1 bc	3.5 b	21.7 a	3.54 a	0.67 a
3	0	Air + 10% CO	0.9 d	3.6 e	20.1 f	3.48 b	0.64 b
		CA + 10% CO	2.3 e	3.5 e	20.8 e	3.61 c	0.64 b
	1	SO_2/F	3.5 f	2.7 f	21.8 d	3.51 b	0.69 c
		SO_2/G	1.8 e	2.8 f	21.9 d	3.47 b	0.63 b
4	0	Air + 10% CO	1.1 g	2.8 g	20.4 i	3.51 d	0.57 d
		CA + 10% CO	3.1 h	3.2 g	20.1 i	3.68 f	0.56 d
	1	SO_2/F	4.5 i	1.7 i	22.0 g	3.63 e	0.63 e
		SO_2/G	2.3 h	2.3 h	21.6 h	3.53 d	0.57 d

[z]Browning scores: 1 = none; 2 = slight; 3 = moderate; 4 = severe; 5 = extreme.
[y]Firmness scores: 1 = very soft; 2 = soft; 3 = intermediate; 4 = firm; 5 = very firm.
[x]Mean separation in columns for each storage duration by LSD test, 5% level.

treatments after oen month in storage in the 1981 study (data not shown). Grapes subsequently kept in air + 10% CO exhibited the least brown discoloration, followed by those kept under CA + 10% CO and SO_2/G treatments (Table 1). SO_2/F-treated berries showed the most severe browning, probably due to accelerated senescence and the extra handling involved in repeated fumigation treatments. After 3 and 4 months in storage, browning of the berries kept in CA + CO was greater than that of berries in the SO_2/G and air + CO treatments (Table 1), which may have been due to elevated CO_2 as has been reported by others (8, 9).

Grapes kept under CO added to air or CA softened at a slower rate than the SO_2-treated grapes (Table 1). No significant differences in pH or TA were noted among treatments after 2 months in storage and SSC was comparable among treatments except for slightly lower SSC values in fruit subjected to air + CO or CA. After 3 and 4 months, SO_2-treated fruit contained more SSC than CO-treated fruit (Table 1), probably due to greater water loss in the SO_2-treatments because of lower relative humidity, especially in the SO_2/F treatment. Differences in pH and TA were small after 3 and 4 months.

In 1982, sensory evaluation using triangle tests showed that after one month of storage, judges were able to differentiate only between the SO/G and the 2% O_2 + 10% CO-treated fruit (data not shown). SO_2-treated berries were scored lower in firmness and higher in browning and bleaching after 2 months than those from the other treatments (Table 2). After 3 months of storage, SO_2-treated fruit were scored higher in browning, bleaching, and sulfury flavor than 2% O_2 + 10% CO_2-treated fruits. CO-treated fruits were scored higher in firmness and lower in browning and bleaching, at the end of 4 months in storage, but were rated slightly higher in off-flavor and sulfury flavor than SO_2-treated berries (Table 2).

In conclusion, 10% CO in a 2% O_2-atmosphere appeared to be the best CA treatment, controlling decay as well as the currently used SO_2 treatments while providing better quality main-

Table 2. Effects of storage conditions on decay incidence and quality attributes of 'Thompson Seedless' grapes (1982 study).

Storage conditions at 0°C				Sensory evaluation scores[z]				
Duration (months)	Treatment	Decay (%)	Flesh firmness (N)	Firmness	Browning	Bleaching	Off-flavor	Sulfury flavor
2	Air control	21.1 c[y]	2.6 c	6.1 a	3.7 a	1.6 a	1.3 a	3.0 a
	2% O_2	9.2 d	3.0 d	6.3 a	1.3 b	1.3 ab	1.7 a	2.9 a
	2% O_2 + 10% CO	0.2 e	3.0 d	6.1 a	1.3 b	0.9 b	1.4 a	4.1 a
	SO_2/G	0.1 e	2.6 c	5.2 b	4.5 a	3.7 c	1.6 a	3.1 a
3	2% O_2 + 10% CO	0.2 f	2.9 e	5.9 c	1.5 c	1.1 d	1.3 b	3.4 b
	SO_2/G	0.1 f	2.8 e	5.8 c	3.6 d	2.3 e	1.4 b	4.4 c
4	2% O_2 + 10% CO	0.4 g	2.5 f	6.1 d	2.6 e	1.4 f	2.4 c	4.6 d
	SO_2/G	0.2 g	2.6 f	5.4 e	5.6 f	2.9 g	1.7 d	3.7 e

[z]Scoring system: 0 = none to 10 = extreme.
[y]Mean separation in columns for each storage duration by LSD test, 5% level.

tenance of grapes than SO_2 during storage for up to 4 months. Further evaluations of the advantages and disadvantages of CO vs. SO_2 in relation to fruit quality and environmental safety considerations must be made before CO can be recommended for long-term storage of grapes.

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