The Quality of Three Table Grape Varieties Fumigated with Methyl Bromide at Doses Recommended for the Control of Mealybugs

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SUMMARY. ‘Ruby Seedless’, ‘Red Globe’, and ‘Prima Red’ table grapes were fumigated with the treatment schedule of the USDA–Animal Plant Health Inspection Service recommended for the control of mealybugs. Methyl bromide was applied at 64 g·m⁻³ (4.0 lb/1000 ft³) for 2 h at 16.1 to 18.3 °C (61 to 65 °F). The grapes were in commercial packages typical for each cultivar. After fumigation and 30 min of aeration, the grapes were stored 2 to 4 weeks at 5 °C (41 °F) and their quality assessed by evaluation of cluster rachis condition, shatter, berry cracking, decay, berry color, internal browning, bleaching injury, and firmness. None of the table grape quality parameters was significantly influenced by methyl bromide fumigation.

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Table 1. Quality parameters and methods employed to evaluate table grape quality after methyl bromide fumigation.

Characteristic	Method of evaluation and units
Stem condition	Visual index of every cluster per box: fresh and green = 2, semidry = 4, dry = 6, very dry = 8.
Shatter	Weight of shattered berries/total cluster weight of every cluster per box.
Cracking	Number of berries cracked/4 kg (8.8 lb).
Decay	Number of decayed berries/4 kg.
Berry color	Color recorded as CIELab color space determined with a Minolta CR-200 surface colorimeter (Minolta Corp. Ramsey, N.J.) of 25 randomly selected berries per box.
Internal browning	Percentage of berries with internal browning per randomly selected sample of 25/box.
Bleaching injury	Visual index of bleaching injury, usually associated with SO ₂ fumigation: none = 0; slight = 1; moderate = 3; severe = 5 of a randomly selected sample of 50 berries/box.
Firmness	Deflection or displacement (mm) of individual berries under 0.68 kg (1.5 lb) force applied by Instron model 4201 materials tester (Instron Corp., Canton, Mass.), per randomly selected sample of 25 berries/box.

Recently, Australia required U.S. shippers to fumigate table grapes exported to that country to control two pests of quarantine concern, the grape mealybug (*Pseudococcus maritimus*) and vine mealybug (*Planococcus ficus*) using a USDA–Animal Plant Health Inspection Service (USDA–APHIS) mealybug fumigation schedule developed for quarantine purposes (USDA–APHIS 1996). Both of these pests occur in the San Joaquin Valley of California. The USDA–APHIS fumigation schedule for mealybug control dictates a higher methyl dosage, but of shorter duration, than that routinely used for fruit fly (*Ceratitis* sp.) control. Chilean grapes imported into the United States are routinely fumigated with methyl bromide using the fruit fly schedule and impacts on grape quality are minor. The fumigation schedule applied for fruit fly control is 32 g·m⁻³ (2 lb/1000 ft³) for 3.5 h, while that for mealybug control is 64 g·m⁻³ (4 lb/1000 ft³) for 2 h. This results in a concentration × time product ≈12.5% higher in the Australian quarantine requirement than for fruit fly fumigation. Exporters are concerned about the impact the mealybug schedule may have on grape quality. Therefore, we conducted a thorough assessment of the influence of this schedule on table grape quality to determine if negative impacts on berry quality might result from its use.

The primary injury caused by methyl bromide to table grapes is internal browning (Auda et al., 1977; Nelson and Spitler 1982). Phillips and coworkers (1984) reported 32 g·m⁻³ (2 lb/1000 ft³) methyl bromide for 3.5 h did not cause internal browning or other injuries to table grapes. However, Nelson and Spitler (1982) reported that this rate increased the incidence of internal browning of ‘Thompson Seedless’ berries when fumigation was four or more hours. Liyanage and coworkers (1993) showed glutathione content was greatly reduced by methyl bromide fumigation, although they did not demonstrate a causative relationship between glutathione reduction and internal browning. Our objective was to evaluate the quality of several popular table grape varieties (‘Red Globe’, ‘Prima Red’, and ‘Ruby Seedless’) after fumigation with 64 g·m⁻³ (4 lb/1000 ft³) of methyl bromide for 2 h.

Materials and methods

The table grapes were obtained from commercial cold storage (0 to 1 °C; 32 to 34 °F); they had been harvested 2 months previously and had SO₂ generator pads within each package. The SO₂ generators were removed from one-half of the ‘Prima Red’ and ‘Red Globe’ packages and all of the ‘Ruby Seedless’ packages. ‘Red Globe’ grapes were in expanded polystyrene (EPS)

boxes with microperforated plastic liners [perforations: 1-mm-diameter (0.04-inch) holes spaced 10 mm (0.4 inch) apart] with no internal packaging around the clusters. ‘Prima Red’ grapes were in expanded EPS boxes, with the same perforated plastic liners, and the clusters were wrapped in tissue paper. ‘Ruby Seedless’ grapes were in technical kraft veneer (TKV) boxes, the box had a vented paper curtain and no plastic liner, and the clusters were wrapped in vented plastic bags.

Two boxes of each combination of variety and package type were fumigated. The table grapes were fumigated in a 0.54-m³ (19.1 ft³) steel chamber at DFA of California in Fresno, California. This chamber exceeds all USDA–APHIS performance requirements for quarantine treatments. The treatment schedule used was USDA–APHIS Schedule T104(a²) for mealybugs. Methyl bromide was applied at 64 g·m⁻³ (4.0 lb/1000 ft³) for 2 h followed by aeration for 30 min.

The load factor in the chamber was higher with ‘Red Globe’ and ‘Prima Red’ grapes than ‘Ruby Seedless’ grapes. Four boxes of each variety were used within the chamber in tests with ‘Red Globe’ and ‘Prima Red’ grapes, which occupied ≈25% of the chamber volume (vol/vol). Two boxes were fumigated within the chamber in tests with ‘Ruby Seedless’ grapes and these occupied ≈8.1% of the chamber volume (vol/vol).

Table 2. Concentrations and sorption of methyl bromide determined during fumigation tests on table grapes using USDA–APHIS treatment schedule for mealybugs (1.0 g·m⁻³ = 1.0 oz/1000 ft³).

Cultivar	Methyl bromide (g·m ⁻³) ^z						
	Initial	0.5 h	1 h	2 h	Sorption (%) ^y	15 min	30 min
Prima Red	72.0	65.4	61.2	50.0	30.6	11.1	2.7
Red Globe	75.1	64.0	58.4	53.0	29.4	5.6	1.4
Ruby Seedless	66.2	64.0	60.4	58.4	11.8	9.7	4.1

^zMethyl bromide concentration inside chamber during aeration.

^yPercentage of original methyl bromide concentration remaining after 2 hours before aeration began.

Table 3. Quality measurements (means $\pm$ SD) of table grapes after methyl bromide fumigation. The methods of evaluation and units of each measurement are described in Table 1. Grapes were stored 2 months at 0 °C (32 °F) before fumigation and 2 weeks at 5 °C (41 °F) plus 1 d at 20 °C (68 °F) after fumigation (1.0 mm = 0.039 inch).

Cultivar	SO ₂	Stem	Shatter	Cracking	Decay	Berry color			Internal	Bleaching	Firmness
	pad	condition		(no.)	(no.)	L	a	b	browning (%) ^z	injury	(mm)
Ruby Seedless-CON ^y	no	3.5 $\pm$ 0.5	0.7 $\pm$ 0.1	1.5 $\pm$ 1.1	4.7 $\pm$ 2.6	28.9 $\pm$ 1.2	6.7 $\pm$ 1.3	1.9 $\pm$ 0.9	14	3.0 $\pm$ 1.4	3.2 $\pm$ 0.4
Ruby Seedless-MB	no	3.3 $\pm$ 0.7	0.7 $\pm$ 0.1	1.7 $\pm$ 0.9	3.8 $\pm$ 1.6	28.9 $\pm$ 1.1	6.3 $\pm$ 1.6	1.8 $\pm$ 1.4	18	2.8 $\pm$ 1.4	3.3 $\pm$ 0.4
LSD (<i>P</i> = 0.05)		NS ^x	NS	NS	NS	NS	NS	NS	NS	NS	NS
Red Globe-CON	yes	4.5 $\pm$ 0.6	0.1 $\pm$ 0.1	0.3 $\pm$ 0.5	1.8 $\pm$ 1.9	32.0 $\pm$ 1.8	13.6 $\pm$ 2.7	4.5 $\pm$ 1.5	6	3.0 $\pm$ 1.4	2.4 $\pm$ 0.5
Red Globe-MB	yes	4.4 $\pm$ 0.2	0	0.1 $\pm$ 0.2	0.8 $\pm$ 0.6	31.1 $\pm$ 1.5	12.2 $\pm$ 2.6	3.8 $\pm$ 1.5	8	2.8 $\pm$ 1.4	2.5 $\pm$ 0.4
Red Globe-CON	no	4.2 $\pm$ 0.6	0	0.1 $\pm$ 0.2	0.6 $\pm$ 0.9	32.7 $\pm$ 1.8	13.4 $\pm$ 2.0	4.5 $\pm$ 1.2	8	2.7 $\pm$ 1.4	3.5 $\pm$ 0.4
Red Globe-MB	no	4.2 $\pm$ 0.8	0.1 $\pm$ 0.1	0.4 $\pm$ 0.7	0.8 $\pm$ 1.5	31.6 $\pm$ 1.7	12.1 $\pm$ 3.0	3.7 $\pm$ 1.3	14	2.3 $\pm$ 1.4	2.5 $\pm$ 0.3
LSD (<i>P</i> = 0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Prima Red-CON	yes	3.6 $\pm$ 0.6	0.6 $\pm$ 0.1	0.8 $\pm$ 1.0	1.8 $\pm$ 1.7	29.3 $\pm$ 1.6	7.9 $\pm$ 1.6	2.9 $\pm$ 1.1	78	2.7 $\pm$ 1.8	3.1 $\pm$ 0.6
Prima Red-MB	yes	3.6 $\pm$ 0.4	0.8 $\pm$ 0.1	0.6 $\pm$ 0.5	1.2 $\pm$ 1.7	29.6 $\pm$ 1.9	8.1 $\pm$ 1.5	3.4 $\pm$ 1.4	74	2.9 $\pm$ 1.3	2.9 $\pm$ 0.5
Prima Red CON	no	4.1 $\pm$ 0.7	0.6 $\pm$ 0.1	0.5 $\pm$ 0.5	1.7 $\pm$ 0.8	29.4 $\pm$ 1.1	7.8 $\pm$ 1.3	2.5 $\pm$ 0.8	90	2.4 $\pm$ 1.4	3.0 $\pm$ 0.6
Prima Red-MB	no	3.6 $\pm$ 0.5	0.7 $\pm$ 0.1	0.5 $\pm$ 0.5	0.8 $\pm$ 0.9	29.3 $\pm$ 1.2	8.4 $\pm$ 1.4	2.6 $\pm$ 0.8	78	2.2 $\pm$ 1.4	3.0 $\pm$ 0.4
LSD (<i>P</i> = 0.05)		NS	NS	NS	NS	NS	NS	NS	NS	0.4	NS

^zEvaluated after 4 weeks at 5 °C (41 °F) after fumigation.

^yCON = untreated control; MB = methyl bromide fumigated.

^xMeans within columns are nonsignificant.

Methyl bromide concentrations during fumigation and aeration were determined by gas chromatography. Samples were withdrawn with a gas-tight syringe and introduced via an integral gas-sampling valve (1 mL loop) into a gas chromatograph (model 1200; Fisher, Pittsburgh, Pa.) using thermal conductivity for detection. The temperatures of the column, detector, and valve were 150 (302 °F), 170 (338 °F), and 170 °C (338 °F), respectively. The helium carrier gas flow rate through the 1.8 m (5.9 ft) long by 4 mm (0.16 inch) diameter Poropak Q column (Millipore Corp., Bedford, Mass.) was 25 mL·min⁻¹ (0.85 fl oz/min) and the retention time for methyl bromide was 1.9 min.

Table grape quality was assessed 2 weeks after fumigation and storage at 5 °C (41 °F), and one additional day at 20 °C (68 °F) by evaluation of cluster stem or rachis condition, shatter, berry cracking, decay, berry color, bleaching injury, and firmness. Internal browning was assessed after 2 to 4 weeks of storage at 5 °C. There were two boxes treated of

each combination of variety and package type. The sampling methods, quality characteristics evaluated, and the units employed are described in Table 1.

Analysis of variance was applied to the units of measurement employed in each quality evaluation. The responses of each 'Red Globe' and 'Prima Red' cultivars were analyzed independently in a two (fumigated or not fumigated) $\times$ two (with sulfur dioxide generator pad or without) design; 'RubySeedless' were analyzed in a one-way design. Results from all cultivars were combined in a three-way analysis of variance to identify significant differences among them. If significant, Fisher's protected least significant difference was calculated (*P* = 0.05) to separate treatment means.

Results

The fumigation simulated a commercial fumigation that would be applied for the control of mealybugs for quarantine purposes. Table 2 shows the concentration of methyl bromide during the exposure period and aeration.

The readings initially were higher than the dose calculated for an empty chamber which indicated chamber volume displaced by the packages. The minimum methyl bromide concentrations as specified by the USDA-APHIS at 0.5 and 2.0 h were exceeded. The methyl bromide concentrations during aeration, shown in Table 2, dropped rapidly and simulated aeration that would occur under commercial conditions. EPS boxes adsorbed more methyl bromide than TKV boxes. The grape and air temperatures during fumigation were 16.1 to 18.3 °C (61 to 65 °F) and were within the specifications of USDA-APHIS for mealybug fumigation.

No quality parameter of the table grapes was significantly influenced by methyl bromide fumigation (Table 3). Sulfur dioxide pads significantly increased berry bleaching only of 'Prima Red' grapes. Quality observations differed significantly among varieties (Table 4).

Discussion

Methyl bromide fumigation did

Table 4. Differences in quality among grape cultivars independent of methyl bromide fumigation. The methods of evaluation and units of each measurement are described in Table 1. Grapes were stored 2 months at 0 °C (32 °F) before fumigation and 2 weeks at 5 °C (41 °C) plus 1 d at 20 °C (68 °F) after fumigation (1.0 mm = 0.039 inch).

Cultivar	Stem condition ^z	Shatter	Cracking (no.)	Decay (no.)	Internal browning (%) ^y	Bleaching injury	Firmness mm
Ruby Seedless	3.3 a	0.71 a	1.6 a	3.0 a	16 a	2.8 ab	3.2 a
Red Globe	4.3 b	0.14 b	0.7 b	1.0 b	9 a	2.8 b	2.4 c
Prima Red	3.7 c	0.65 a	0.6 b	1.4 b	80 b	2.5 a	3.0 b

^zMeans within columns followed by unlike letters are significantly different (*P* = 0.05) by Fisher's protected LSD.

^yEvaluated after 4 weeks at 5 °C (41 °F) after fumigation.

not affect any quality parameter of the table grapes in our tests, and our results are similar to those of Phillips and coworkers (1984) who evaluated the impact of the fruit fly methyl bromide schedule on the quality of 'Thompson Seedless', 'Perlette', 'Flame Seedless', and 'Cardinal' grapes. Several aspects of our study differ from that of Phillips and coworkers (1984): we evaluated a higher methyl bromide dose and we stored the grapes for 1 month after fumigation, rather than 6 d, before we assessed internal browning. Because internal browning requires time to develop (Nelson and Spitler, 1982), we evaluated internal browning after a period that simulated the duration and temperatures typical of export marketing. Several authors reported the development of internal browning of grapes and other fruit to be associated with methyl bromide fumigation (Liyanage et al., 1993). Auda and coworkers (1977) reported that methyl bromide fumigation exacerbated internal browning of grapes but was not the cause of the disorder itself, and that browning increased with longer storage times. Nelson and Spitler (1982) observed internal browning of 'Thompson Seedless' berries after fumigation with $32 \text{ g}\cdot\text{m}^{-3}$ ($2 \text{ lb}/1000 \text{ ft}^3$) of methyl bromide for four or more hours when evaluated after 2 weeks at 0°C (32°F) and 1 d at 20°C (68°F). They stated that factors, in addition to methyl bromide fumigation, can cause the browning of the berries, such as delayed cooling, high temperatures, slow cooling rates, long storage periods, extended market period and injury from rough handling. Furthermore, they found that these stress factors are additive: one stress may not cause visible browning, but in conjunction with one or more other factors the browning may become evident. We observed some browning among the berries, particularly 'Prima Red' seedless, but it was not associated with methyl bromide fumigation and may have occurred during the long storage (2 months) of the grapes used in our tests. Also, internal browning is not as readily apparent in highly pigmented cultivars as it is with less pigmented cultivars such as 'Thompson Seedless'.

Packaging influenced the dosage of methyl bromide within the boxes. EPS boxes absorbed more methyl bromide than did TKV boxes, although the

available dosage was within the minimum required for control of mealybugs. Harris et al. (1984) showed more methyl bromide was sorbed by the EPS than TKV or fiberboard boxes, and that after fumigation, significantly more methyl bromide was released from the EPS boxes during aeration. In their work, methyl bromide dosages with grapes packaged in TKV or fiberboard boxes, that were sufficient to obtain minimal levels required for the control of fruit flies for quarantine purposes, were too low when applied to EPS packages. Under commercial conditions, it may be necessary to separate the grapes according to package type and increase the methyl bromide dose applied when EPS boxes are fumigated.

In this work, we show for the first time that methyl bromide fumigation using the USDA-APHIS mealybug schedule ($64 \text{ g}\cdot\text{m}^{-3}$ or $4.0 \text{ lb}/1000 \text{ ft}^3$ for 2 h) did not injure the grapes by any of the measures of quality applied, and the risk of berry injury by this treatment is probably low. This risk is further reduced if the grapes are promptly cooled after harvest, storage periods are not excessive, and rough handling is avoided.

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