Carbon dioxide fumigation of processed dried vine fruit (sultanas) in sealed stacks

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Abstract

Dried vine fruit, in Australia, is disinfested with ethyl formate and methyl bromide. Alternative disinfestation techniques for methyl bromide are being sought, and laboratory studies indicate carbon dioxide may be suitable. This paper describes two trials to test the feasibility of storing sultanas under sealed plastic membranes with an initial disinfestation using carbon dioxide.

The stacks were dosed at different rates, which gave 100% mortality of test insects (*Oryzaephilus surinamensis, O. mercator, Plodia interpunctella, Tribolium confusum* and *T. castaneum*) placed inside the cartons of fruit.

There was no evidence that condensation occurred during the periods of sealed storage, which lasted for 60 and 50 days, respectively. Organoleptic testing of samples, taken before and after the trials, indicated that sultana quality was unaffected by the treatment. The trials demonstrated that sealed stack storage has potential for long-term storage of large stacks of dried vine fruit.

Introduction

Dried vine fruit (currants, raisins/lexias, sultanas) is very susceptible to insect infestation during storage and transport. Over 20 insect species have been found infesting these products in Australia. The major pests are *Oryzaephilus surinamensis, O. mercator, Plodia interpunctella,* and various *Ephestia* spp. Other pests include *Tribolium castaneum, T. confusum, Carpophilus hemipterus* and *Drosophila melanogaster* (Tarr and Hilton, unpublished data).

The Australian dried fruit industry takes positive steps to prevent infestation of its product. Pest control methods applied include pre-packaging fumigation with ethyl formate and post-packaging fumigation with methyl bromide where stocks may be stored for prolonged periods. However, the industry seeks to reduce its use of chemicals that may leave undesirable residues. This objective, together with concern about environmental damage caused by methyl bromide, and potential restrictions on its production and availability, have led to investigation of alternative pest control measures. Attention has focused on modified atmospheres because of their minimal impact on the environment, greater worker safety, and because they leave no undesirable residues.

Initial studies have shown that sultanas stored in atmospheres up to 99% carbon dioxide (CO_2) for six months, produced no off-flavours or odours, and CO_2 had no deleterious effect on product colour, even at high temperatures (35°C).

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All the major insect species infesting dried vine fruit in Australia are reported to be controlled by high CO_2 atmospheres (Annis 1987), except *Carpophilus hemipterus,* which has not been investigated. However, this gas has been used successfully to disinfest sultanas (van S. Graver and Hilton, unpublished data) in a sealed freight container using the method described by Banks (1988).

The commodity is usually packaged, after processing, in polyethylene-lined 14 kg cardboard cartons and stored in large stepped, 100–160 tonne stacks of tightly packed cartons (Figs 1 and 2). Carbon dioxide has the advantage that it can be used with little modification to current storage practice, by sealing carton-stacks of dried fruit in plastic membranes (Annis and van S Graver 1990). In situations where long-term storage (up to 18 months) is envisaged, the advantage conferred by storage within an insect-proof enclosure obviates the need for repeated treatments (Annis and van S. Graver 1987). The method also requires lower initial carbon dioxide gas concentrations than other modified atmospheres to obtain a successful treatment (Freidlander 1984).

The objective of the work reported here was to demonstrate that large stacks of packed sultanas could be disinfested with CO_2 and stored under sealed plastic membranes, without deleterious effects on the commodity.

Materials and Methods

Two trials were held in 1992. Each represented a different stacking configuration common in packing sheds and a different sealing system. The methodology used in both cases is described in full by Annis and van S. Graver (1990). After sealing, each stack was monitored for changes in CO_2 concentration and relative humidity. Bioassays were placed in each stack and removed after unsealing.

Trial 1

This trial was conducted from 1 April to 1 June 1992. One stack of 125 t of dried sultanas was used. The cartons, unitised on slip sheets (72 cartons per unit) and wrapped in stretch wrap (linear low density polyethylene), were stacked directly on the floor sheet. The stack was 10 m long, 6 m wide, and 3.6 m high (with a step at 2.1 m). To enhance gas distribution, a plenum was formed at floor level by laying a row of pallets along the central longitudinal axis of the stack (Fig. 1).

In this trial the cover sheet was sealed to the floor sheet with PVC solvent glue (Annis and van S. Graver 1990). The sheeted, sealed and pressure-tested stack was dosed with CO_2 delivered from a bulk tanker through a heat exchanger. Gaseous CO_2 was preferred to snow shooting because of the unknown effects of the freezing temperatures (–78.5°C) of CO_2 snow on the commodity and packaging.

Trial 2

This trial was conducted from 9 July to 19 September 1992. One stack of 139 t of dried sultanas was used. The stack con-

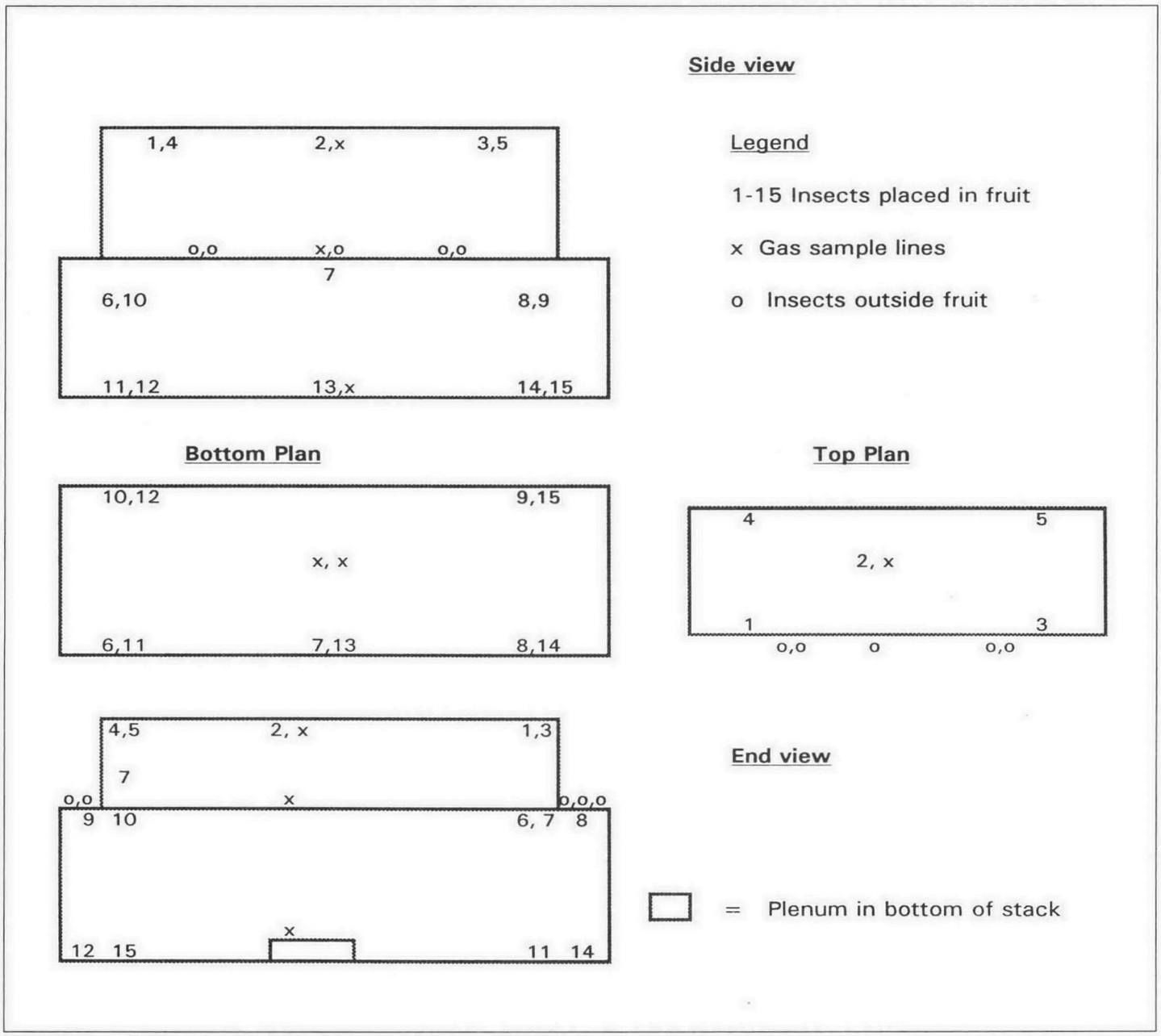

Fig. 1. The positions of insect cultures and gas sample lines in Trial 1.

sisted of 9955 cartons stacked with four receding steps, each step one or two cartons wide. The cartons were hand stacked directly onto the floor sheet. To assist gas distribution, a 10–15 cm space, extending from the floor to the top of the stack, was left through the axis on both sides of the stack (Fig. 2).

The sheeted stack was sealed using a system of clamps and lengths of square-section pipe. Pressure applied by the clamps to the piping (laid along the periphery of the sheets), against the warehouse floor, held and sealed the sheets together.

The sheeted, sealed and pressure-tested stack was dosed with CO_2 delivered from a portable pallet tank through a heat exchanger. As in the previous trial, gaseous CO_2 was preferred to snow shooting.

Bioassays

Insect cultures for bioassay were placed in the cartons under 5–10 cm of fruit, with the inner polyethylene liner refolded and the cartons located at various positions in the stack (Figs 1 and 2). The insects, in 50 g of rearing medium, were held in chromed steel cages fitted with 60 gauge mesh gauze windows. The same species (*Oryzaephilus surinamensis, O. mercator, Tribolium castaneum, T. confusum* and *Plodia interpunctella*), were used in the both trials, with the exception of *Oryzaephilus mercator*, which was unavailable for the second trial.

The insects were reared on unprocessed dried vine fruit at 27°C and 60% r.h. at CSIRO Division of Entomology, Canberra, in a controlled temperature (CT) room. The day before each trial, 400 g whole cultures of each species containing all stages of development were divided into eight 50 g subsamples. Five subsamples were selected randomly as test (3), field control (1), and laboratory control (1), and the remainder discarded. The laboratory control for the first stack was held in the CT room, and for the second stack at the CSIRO Division of Horticulture, Merbein, in a CT room at 27°C and 50% r.h. for the duration of the trial.

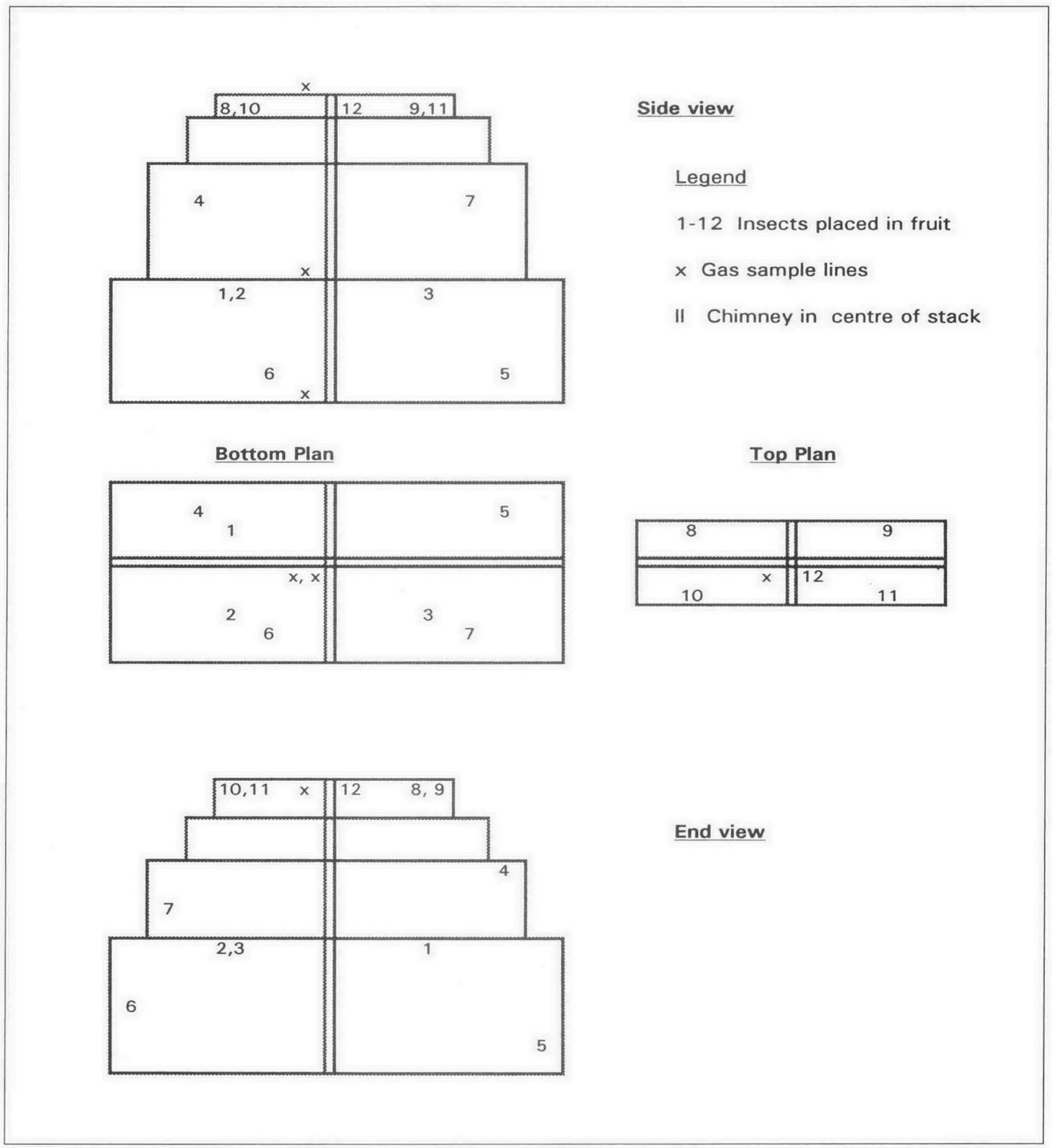

Fig. 2. The positions of insect cultures and gas sampling lines in Trial 2.

Test and field control samples were transported in an insulated box to the trial sites. Test samples were placed within the cartons in the stack, and field control samples taken to the CSIRO Division of Horticulture and held at ambient conditions for the remainder of the trial. These controls were not held at the site because of the risk from routine pest control measures that might have affected their value.

After 60 days, the first stack was opened and the insect samples collected and sent with field controls to CSIRO Division of Entomology for assessment. The second stack was opened after 50 days, and insect samples collected and taken for assessment to the CSIRO Division of Horticulture. Samples from the centre of the stack could not be removed for a week because of their inaccessibility. However, assessment and incubation were as with other test samples.

Assessment of test and control insects was made by hand sorting the samples and recording stages (adult, larvae or pupae) as alive or dead. Samples were reassessed after 30 days of incubation in the CT room to check for survival of immature stages in both cases.

Sample cultures of 200 g were also exposed in containers outside the dried fruit cartons (see Fig. 1) in the first trial. These were used as demonstration cultures at an industry meeting and were not incubated further.

Carbon dioxide concentrations and relative humidity in the enclosures

The stacks were dosed with CO_2 until gas concentrations at the top purge vent were greater than 80%. These dosages were 550 and 250 kg of CO_2/stack, respectively.

In both trials, initial determinations of the CO_2 concentration in the air purged from the stacks during dosing were made with a Riken gas interferometer.

Thereafter, for the duration of the storage period, CO_2 concentrations within the enclosures were monitored using Dräger CO_2 5%/A tubes (Cat. no. CH 20301). These tubes are able to measure CO_2 concentrations between 5 and 60%. Samples for this purpose were drawn through 2 mm internal diameter nylon piping from positions at the bottom, centre and top of the stack (Fig. 1).

In the first trial, the relative humidity within the enclosure was determined similarly, using Dräger water vapour (8101081) tubes (1–18 mg/L).

Quality assessment

In both trials fruit samples were taken for quality assessment before and after treatment. Samples were removed from the bottom, corners and sides of the stack. Taste testing of the samples taken from the stacks was conducted approximately one month after unsealing each stack and was based on a forced choice triangle test (ASTM 1968). The panel of 12 tasters was presented with four successive triangle tests. The tasters were required to identify the sample they believed to be different and state which taste, if any, they preferred. Comments on taints were encouraged as any unusual taste may have been attributable to the solvent glue used in the first trial, not the effect of CO_2 on the fruit.

Results and Discussion

Pressure tests

Both stacks successfully passed two pressure decay tests (Annis and van S. Graver 1990) before dosing with CO_2. Pressure decay halving times from 800 to 400 pa of 22, 24 and 34, 29 minutes were obtained in trials 1 and 2, respectively. These values are more than double the required standard, indicating that the membranes had been sealed effectively.

Carbon dioxide concentrations and relative humidity

Carbon dioxide concentrations obtained within the enclosures are displayed in Figure 3. These data were obtained using Dräger detector tubes, which have an upper limit of 60%. Thus, concentrations above this can only be interpolated. It can be seen that the requirement for CO_2 concentrations to be maintained above 35% at 15 days or longer (Banks et al. 1980; Annis and van S. Graver 1990) was successfully achieved in both trials.

The first stack was dosed with 550 kg of CO_2 (equivalent to 3.4 kg/t) with the concentration not falling below 35% after 60 days storage. This well-sealed stack would have been suitable for long-term storage.

The dose applied to the second stack was considerably lower — 250 kg of CO_2 (equivalent to 1.7 kg/t). This may be attributable to the spaces built along the axes of both sides of the stack. These were intended to assist the distribution of the gas inside the enclosure. However, a rapid rise in CO_2 concentration was detected during the purge, possibly because the gas was funnelled directly to the top of the enclosure. This led to a premature halt to dosing and was responsible for the lower gas concentrations achieved during the trial. Nonetheless, the CO_2 concentration was held above 35% for 21 days. Thus, both treatments were successful.

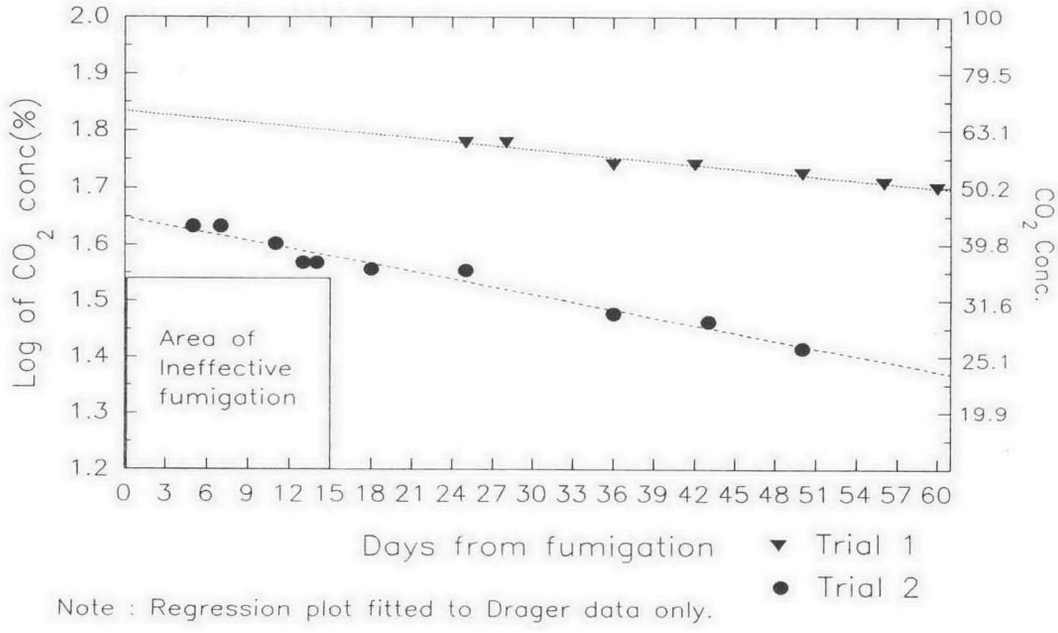

Fig. 3. Carbon dioxide concentrations in a sealed stack of sultanas following fumigation.

Water vapour readings were used as a guide to relative humidity changes in the first trial. The results are shown in Figure 4. It can be seen that water vapour changes within the enclosure resembled ambient water vapour changes. No moisture accumulation occurred during the trial, and since water vapour within the enclosure remained similar to external water vapour no moisture accumulation is expected to occur in future trials.

Bioassays

Insect mortalities in the first trial are given in Table 1. The treatment gave 100% mortality of all life stages of all cultures. Insect mortalities of the second trial were 100% for all adults, pupa and large larva present, but after the 30-day incubation a few small, immature larvae were found (Table 2), giving total mortalities of between 100 and 89.9%. However, all cultures from the second trial had been incubated together and it was found that *O. surinamensis* had escaped through the 60 gauge mesh, with five adults from the controls found wandering amongst the samples. Subsequent reincubation of all immatures found in culture samples demonstrated that 'survivors' were all *O. surinamensis* regardless of the origin of the culture. Thus, it was concluded that the 'survivors' were offspring of the loose *O. surinamensis* or escapees from the controls.

We believe that a dose between the two used in these trials should produce desirable results with an economic advantage over the first trial's high dosage levels and a more certain insecticidal result than the second trial.

Table 1. Test insect mortalities in Trial 1.

Species	Adults	Larvae	Pupae	Adults	Larvae	Pupae	Total live insects	Mortality (%)
		Alive			Dead			
P. interpunctella								
Test	0	0	0	1	100	2	0	
Control	0	13	2	3	78	3	15	100
T. castaneum								
Test	0	0	0	34	96	0	0	
Control	16	34	0	6	5	0	50	100
T. confusum								
Test	0	0	0	183	276	2	0	
Control	205	118	0	8	0	0	323	100
O. mercator								
Test	0	0	0	423	19	0	0	
Control	327	45	7	48	1	0	379	100
O. surinamensis								
Test	0	0	0	317	20	1	0	
Control	352	32	3	45	0	0	387	100

Table 2. Test insect mortalities in Trial 2.

Species	Adults	Larvae	Pupae	Adults	Larvae	Pupae	Total live insects	Mortality (%)
		Alive			Dead			
P. interpunctella								
Test	0	0	0	0	77	7	0	
Control	0	43	0	0	76	9	43	100
T. castaneum								
Test	0	4	0	170	94	35	4[a]	
Control	189	562	10	137	0	2	761	99.47
T. confusum								
Test	0	2	0	47	5	0	2[a]	
Control	17	1	0	14	0	0	18	88.89
O. surinamensis								
Test	0	1	0	127	17	11	1[a]	
Control	108	88	1	54	4	0	197	99.49

[a]All larva found were early stage *O. surinamensis*, indicating contamination late in incubation.

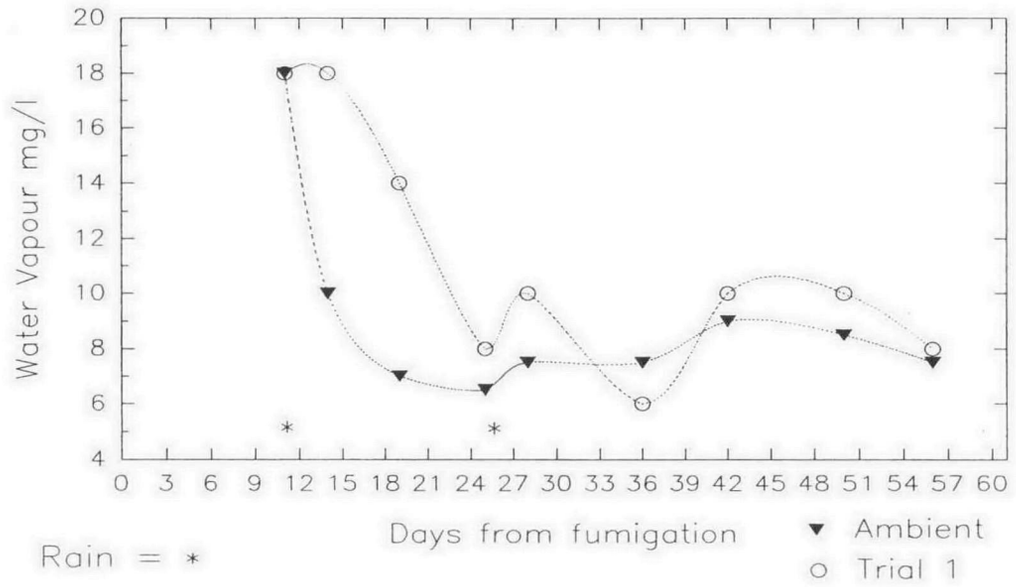

Fig. 4. Change in water vapour in a sealed stack of sultanas, compared with ambient water vapour.

Quality assessment

Fruit quality was unaffected by the treatment. The tasting panel could not differentiate between treated and untreated sultanas for either taste or taint. No change in colour was observed. Previous work by Tarr and Hilton (unpublished data) had shown that there was no significant deleterious effect on the colour of dried sultanas of a similar quality exposed at 15 or 35°C to high CO_2 concentrations for up to 6 months.

Conclusion

Disinfestation with CO_2, followed by storage under sealed plastic membranes, has potential application for dried vine fruit. The technique has a number of advantages over the current practice of sheet fumigation with methyl bromide. It eliminates a number of worker safety problems; particularly the hazards associated with working close to stacks while they are being fumigated and during the subsequent ventilation. Carbon dioxide has minimal impact on the environment and provides a residue-free treatment, which is increasingly advantageous in the markets for Australian dried fruit.

Acknowledgments

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