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Tolerance of tropical fruits and a flower to carbonyl sulfide fumigation

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Abstract

The tolerance of 'Apple' banana (*Musa* sp.), avocado (*Persea americana* Mill.), mango (*Mangifera indica* L.), papaya (*Carica papaya* L.), and red ginger (*Alpinia purpurata* (Vieill.) K. Schum) inflorescences to carbonyl sulfide (COS) fumigation was studied. Commodities were exposed at 25°C to COS at various concentrations (1–6% (v/v) for banana; 1% and 2% for the other fruits for various times from 1 to 24 h. Fumigation of bananas with 4% for 1.5 h, 2% for 2.5 h and 1% for 4 h did not cause significant skin or flesh injury when evaluated 7 d after treatment. Fumigated bananas and mango softened faster than unfumigated fruit when the treatment did not cause severe skin injury When the dosage and exposure time were increased for these fruit and the treatment caused severe or extreme skin injury, softening was delayed. COS treatments retarded papaya fruit skin coloration and flesh softening, while it promoted avocado softening. Avocado tolerated 1% for 7 h and 2% for less than 4 h, while mango tolerated 1% for 3 h and 2% for 1 h and papaya 1% for 16 h. Red ginger inflorescences were less tolerant of COS than fruit, being able to withstand 2% for less than 0.75 h and 1% for less than 2 h. COS may be suitable as a fumigant for surface insects on papaya and avocado. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

Fumigation is one of the most practical and convenient methods for insect disinfestation of fresh horticultural products (Paull and Armstrong, 1994). Nevertheless, insecticidal fumigants are toxic to mammals and many are flammable. Ethylene dibromide (EDB) was the most com-

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Table 1
Skin injury and flesh firmness of 'Apple' banana 7 d after exposure to COS fumigation treatment

Experiment	COS % (v/v)	Exposure time (h)	Skin injury (%)[a]	Flesh firmness (N)[b]
1	0	2.5	1	10.4 ± 1.1
	4	2.5	24	8.1 ± 0.8
		2.0	7	7.9 ± 0.7
		1.5	2	8.0 ± 1.0
2	0	7.0	2	12.4 ± 1.7
	2	7.0	35	8.4 ± 0.8
		5.0	24	8.6 ± 0.6
		3.0	5	8.4 ± 0.8
3	0	5.0	1	14.4 ± 8.5
	1	5.0	10	9.0 ± 0.6
		4.0	2	9.0 ± 0.5
		3.0	1	9.1 ± 1.3
4	0	4.0	1	16.6 ± 10.6
	1	4.0	1	11.4 ± 5.7
	2	2.5	1	9.8 ± 1.5
	4	1.5	1	8.8 ± 1.1

[a] The weighted means percentages reported were calculated from the transformed rating scale.
[b] Mean ± standard deviation.

monly used fumigant before being banned in 1984 by the USA Environment Protection Agency because of cancer risks (Anonymous, 1984). The alternatives, hydrogen cyanide (HCN) and phosphine (PH3) have only limited use because of phytotoxicity. Methyl bromide (MB) will be probably withdrawn in the near future as an ozone depletor (Anonymous, 1992).

A new fumigant, that is less toxic to mammals and does not harm the environment is needed to replace present fumigants. Carbonyl sulfide (COS) is a potential alternative for insect disinfestation, as it can effectively control some species of grain insects (Desmarchilier, 1994) and has been patented by the Australian Commonwealth Scientific and Industrial Research Organization (International Patent Application, PCT/AU93/00018). This fumigant is a trace gas in earth's atmosphere and is the major natural sulphur species in the atmosphere (Mihalopoulos et al., 1989). Its environmental fate has been reviewed (Kluczewski et al., 1985), and its decomposition in plants (Taylor et al., 1983) and phytotoxicity to bean plants studied (Taylor and Selvidge, 1984).

We report the possibility of using COS as a fumigant for insect disinfestation of fresh tropical horticultural commodities. 'Apple' bananas, avocado, mango, papaya, and red ginger inflorescences were exposed to various COS concentrations and exposure times. The effect of COS on ripening, skin injury, flesh firmness and appearance, and vase life of red ginger inflorescences was determined.

2. Materials and methods

Mature green 'Apple' bananas (cv. 'Santa Catarina Prata') were harvested from the Waimanalo Experiment Station, on the island of Oahu. Six clusters, (each with three fingers) were fumigated at ≈25°C in a 0.028 m^3 chamber; load factor ≈7 kg m^{-3}. The chamber was modified fiberglass vacuum desiccator (Labconco, Kansas City, Missouri) in which an electrically driven fan was used to ensure adequate circulation of gas within the enclosure and the vacuum ports modified to allow injection of COS using a syringe. Samples were exposed to 1%, 2%, 4% and 6% (v/v) COS for 1–24 h. The required volume of COS (96+%) from a lecture bottle (Aldrich Chemical CO., Milwaukee, WI) was injected. After fumigation, fruit were aerated for 1 h before being allowed to ripen at 22°C. Skin discoloration

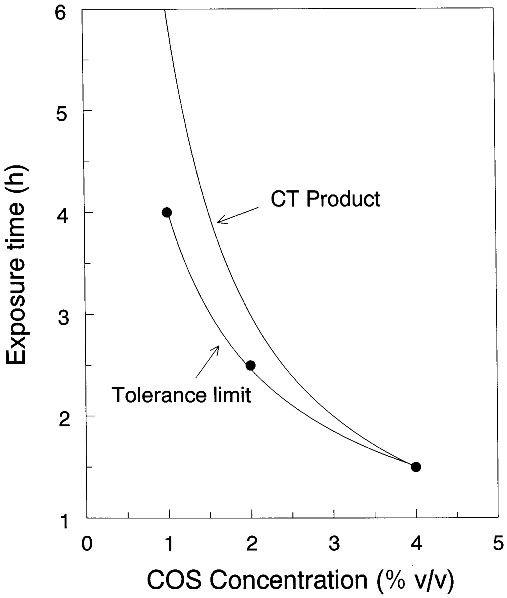

Fig. 1. The tolerance limit of 'Apple' banana exposed to COS fumigation at different concentrations (v/v) and exposure times at a 7 kg m^{-3} load factor. The CT product of the fumigant concentration by exposure time that gave a value of 6% h was plotted for comparison.

was subjectively evaluated 7 d after treatment, using percentage of affected skin area and a rating scale (0, no injury; 1, 0–15%; 2, 16–50%; 3, 51–85%; 4, 86–100% injury). Flesh firmness was measured 7 d after treatment with a penetrometer fitted with a 8 mm diameter tip.

Mature green avocado cv. 'Greengold', mango cv. 'Odorata', and papaya cv. 'Sunset' were harvested from the Poamoho Experiment Station on the island of Oahu. Eight fruit per treatment were fumigated in 0.028 m^3 chambers at 25°C with load factors of ≈ 9 kg m^{-3} for avocado, 10 kg m^{-3} for mango, and 11 kg m^{-3} for papaya. Samples were exposed to 1% and 2% (v/v) COS for 1–24 h, with separate treatments being in one of up to four chambers. After fumigation, fruit were aerated for 1 h before being allowed to ripen at 22°C. Treatments were repeated in a series of four experiments to determine the injury threshold. Skin discoloration was subjectively evaluated 7 d after treatment for avocado and papaya, and 6 d after treatment for mango, using a percentage of affected area and a rating scale (0, no injury; 1, 0–10%; 2, 11–35%; 3, 36–65%; 4, 66–90%; 5, 91–100% injury). Flesh firmness was measured 7 d after treatment for avocado and papaya, and 6 d after treatment for mango, with a penetrometer fitted with a 8 mm diameter tip.

Red ginger inflorescences were harvested from the Poamoho Experiment Station. Ten flowers per

Table 2
Skin injury and flesh firmness of papaya 7 d after exposure to COS fumigation treatment. Skin injury was the percentage of area showing darkening injury using a pre-transformed rating scale from 0 to 5 (no injury to 100% injury)

Experiment	COS % (v/v)	Exposure time (h)	Skin injury (%)[a]	Flesh firmness (N)[b]
1	0	16	0	2.8 ± 1.4
	1	12	0	2.4 ± 0.6
		14	0	2.6 ± 0.6
		16	0	2.4 ± 0.5
2	0	20	0.5	2.3 ± 0.5
	1	16	1	3.7 ± 0.5
		18	10	4.1 ± 0.8
		20	3	5.1 ± 1.1
3	0	12	0.5	1.8 ± 0.2
	2	4	0.5	3.8 ± 2.4
		8	2	3.7 ± 2.8
		12	6	3.2 ± 0.6
4	0	10	1	1.9 ± 0.4
	2	6	16	2.6 ± 1.2
		8	11	2.5 ± 0.5
		10	18	2.8 ± 0.5

[a] The weighted means percentages reported were calculated from the transformed rating scale.
[b] Mean ± standard deviation.

Table 3
Skin injury and flesh firmness of mango 6 d after exposure to COS fumigation treatment

Experiment	COS % (v/v)	Exposure time (h)	Skin injury (%)[a]	Flesh firmness (N)[b]
1	0	8	0	14.9 ± 12.9
	1	4	32	17.2 ± 11.0
		6	86	38.0 ± 10.8
		8	100	45.1 ± 7.6
2	0	4	0	9.0 ± 3.4
	2	2	23	9.3 ± 2.8
		3	37.5	42.8 ± 11.2
		4	77	53.0 ± 7.6
3	0	4	0	16.4 ± 8.1
	1	2	0	11.6 ± 3.5
		3	2	14.5 ± 5.3
		4	29	26.5 ± 12.8
4	0	2	0	19.4 ± 14.5
	2	1	3	8.9 ± 2.7
		1.5	6	11.9 ± 6.5
		2	16	21.8 ± 14.9

[a] The weighted means percentages reported were calculated from the transformed rating scale.
[b] Mean ± standard deviation.

treatment were fumigated in a 120 m^3 chamber with a load factor of ≈ 1 kg m^{-3}. The chamber was constructed locally from lucite, with an electrically driven fan used to ensure adequate circulation of gas within the enclosure and a septum injection port. Samples were evaluated daily for injury and a loss of quality. Days from harvest to when 50% of area of an individual inflorescence was wilted or discolored was regarded as the end of vase life. Treatments were repeated in a series of experiments to determine the injury threshold.

3. Results and discussion

Exposing bananas to 6% COS for 12 h caused severe brown–red discoloration of the skin and retarded flesh softening when evaluated 7 d after

Table 4
Skin injury and flesh firmness of avocado 7 d after exposure to COS fumigation treatment

Experiment	COS % (v/v)	Exposure time (h)	Skin injury (%)[a]	Flesh firmness (N)[b]
1	0	7	0	47.0 ± 30.9
	1	5	0	4.8 ± 0.8
		6	0	5.2 ± 0.8
		7	0	5.1 ± 0.3
2	0	12	0	33.8 ± 32.1
	1	8	34.5	5.6 ± 0.8
		10	34.5	5.6 ± 0.5
		12	32	5.4 ± 0.9
3	0	8	1	10.2 ± 8.0
	2	4	6	6.1 ± 1.4
		6	44	6.0 ± 0.4
		8	44	5.6 ± 0.6

[a] The weighted means percentages reported were calculated from the transformed rating scale.
[b] Mean ± standard deviation.

Table 5
Vase lives of red ginger inflorescences exposed to COS fumigation

Experiment	COS % (v/v)	Exposure time (h)	Vase lives (d)[a]
1	0	2	16 ± 5
	1	2	13 ± 5
2	0	1	20 ± 4
	2	1	12 ± 2
3	0	0.75	18 ± 5
	2	0.75	14 ± 5

[a] Mean $\pm$ standard deviation.

treatment (data not shown). Longer exposure at 6% for 24 h caused extreme skin injury, completely inhibited flesh softening and caused off-flavor. Shorter exposure at 2% for 2.5 h or 4% for 1.5 h did not cause significant skin or flesh injury, with 2% for 3 h or 4% for 2 h and 2% for 5 h and 7 h or 4% for 2.5 h causing only slight and moderate skin injury, respectively (Table 1). Exposure to 1% for 4 h did not cause significant skin injury while 1% for 5 h caused slight skin injury (Table 1). Some samples had slight peduncle injuries when fumigated at these lower rates. The tolerance limit for 'Apple' banana was found to be 4% for 1.5 h, 2% for 2.5 h and 1% for 4 h (Table 1). Fumigated banana softened faster than unfumigated fruit when the COS did not cause severe skin injury. Exposure time influenced the tolerance of 'Apple' banana to COS fumigation more than concentration (Fig. 1). This result was consistent with the responses of fruit to other fumigants such as methyl bromide (Claypool and Vines, 1956), and phosphine (Seo et al., 1979). 'Apple' banana tolerance to COS was low at the lower concentration, tolerating only 4 h at 1% (Fig. 1), whereas, the fumigant concentration by exposure time product of 6% h ($4 \text{ h} \times 1.5\%$) would suggest a tolerance of 6 h at 1%.

Papaya tolerated 16 h exposure to 1% at a loading factor of ≈ 11 kg m^{-3}. There was slight skin injury after 6 h at 2% (Table 2), an olive–gray skin darkening being observed. COS treatments retarded papaya fruit softening (Table 2) and skin coloration. Mango was more sensitive than papaya being only able to withstand 1% COS for less than 3 h and 1 h at 2% (Table 3), the skin showing a blotchy gray–green skin discoloration. The treatments that caused slight skin injury promoted fruit softening, while treatments that caused moderate or severe skin injury retarded fruit softening (Table 3) and caused off-flavor. Avocado treated with 1% COS for 7 h showed no skin injury while 2% for less than 4 h showed very slight skin injury (brown–red discoloration) (Table 4). Treating avocados with COS promoted fruit softening (Table 4). Avocado treated with COS were more susceptible to fruit rot that masked COS induced skin injury.

Red ginger flower tolerated less than 2 h at 1% COS and less than 0.75 h at 2% (Table 5). The red color of flower bracts turned purple in severe cases of COS phytotoxicity. There was seasonal variation in responses of ginger flowers to COS. In preliminary studies, Dendrobium orchid flower sprays were able to tolerate 2% COS for 1.5 h. Adult aphids on red ginger inflorescences were apparently controlled by 2% COS for 1.5 h in initial observations.

The low load factor (less than 12%) used in this study caused the COS concentration to remain nearer to its initial concentration and would be expected to cause more severe injury to commodities than the higher load factor anticipated in a commercial operation. This greater injury would be expected as more fumigant would be available per unit mass of fruit for absorption and hence higher absorbed residues on the fruit. It is also necessary to determine the COS residues after treatment before formal taste panel studies are performed or this fumigant is used commercially. At dose levels that caused noticeable skin injury, off-flavors were detected in the flesh in informal tasting, while none was apparent in treated fruit not showing skin injury.

The surface stages of some species of grain insects are controlled by a 24 h exposure to 0.0025 kg m^{-3} ($\approx 1\%$) (Desmarchilier, 1994). Insect stages that are inside a product are assumed to need longer exposure time or higher concentrations as different species of insects have different susceptibility to COS (Desmarchilier, 1994). The authors are not aware of any studies that report the toxic level of COS on fruit fly eggs or larvae in fruit. The tolerance limit of lethal dose (Fig. 1) for banana fruit suggests that the 1% (v/v) for 4 h may not provide surface insect control for this fruit. Fresh commodities having either thick or dry skin (e.g. nuts), or only requiring the control of surface insects could be fumigated with COS. It may be therefore suitable for surface insects on papaya, avocado and some flowers.

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