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Carbon Dioxide as a Potential Fumigant for Termite Control

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Abstract: Formosan subterranean termites, *Coptotermes formosanus* Shiraki, were exposed to ≧ 95% or 50% carbon dioxide atmospheres for intervals of 24–120 h at 26(±3)°C. A 24-h exposure to ≧ 95% carbon dioxide caused significant termite mortality, but 60 h were required for complete mortality. Exposure to 50% carbon dioxide for 60 h resulted in approximately 70% termite mortality, while complete mortality was recorded after 120 h. When termites were sealed in wooden blocks (90 × 90 × 152 mm), 72–96 h exposure to ≧ 95% carbon dioxide was necessary for complete control. A limited study with *Cryptotermes brevis* (Walker) suggested that this drywood termite is also susceptible to carbon dioxide fumigation, although slightly longer exposures may be required than with *C. formosanus*. Carbon dioxide-modified atmospheres are a viable alternative to conventional fumigants for vault fumigation of termite-infested materials, and may also be applicable to larger-scale fumigations to control structural pests.

Key words: *Coptotermes formosanus*, modified atmosphere.

1 INTRODUCTION

Fumigation is an important tool for the control of termite and wood-boring beetle infestations. Drywood termites (Isoptera, Kalotermitidae), such as *Cryptotermes brevis* (Walker), are the principal targets of structural fumigations in North America and Hawaii.[1] However, fumigants are also used to control above-ground and shipboard infestations of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Rhinotermitidae).[2,3] Where sufficient moisture exists in a structure or nautical vessel, *C. formosanus* colonies can develop and persist independent of ground contact. Above-ground structural infestations of *C. formosanus* are relatively common, and may result either from fragmentation of a colony originating in the soil beneath the structure, or from alates (winged reproductive forms) nesting in an aerial site.[4,5]

C. formosanus colonies, or viable fragments of such colonies, are readily transported in infested utility poles, wooden crates, pallets, and other shipping materials.[5] Thus, fumigation of such materials may be required for quarantine purposes. The fumigants methyl bromide and sulfuryl fluoride are commonly used in both structural and commodity fumigations for termite control. With both fumigants, care must be taken to avoid undesirable reactions with food commodities and to aerate fumigated materials thoroughly.[6–8]

Recent regulatory pressures affecting the use of methyl bromide have stimulated interest both in increased use of sulfuryl fluoride[9] and in possible applications of the inert fumigants carbon dioxide[10] and nitrogen[11,12] in structural pest control. Inert fumigants have a history of successful use in controlling insects in stored food commodities.[13–15] In the present study, we investigated the use of atmospheres modified by high concentrations of carbon dioxide to control infestations of *C. formosanus*.

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2 MATERIALS AND METHODS

2.1 Direct exposure to carbon dioxide

All fumigation studies were conducted at the United States Department of Agriculture, Agricultural Research Service (USDA-ARS) Tropical Fruit and Vegetable Research Laboratory, Hilo, Hawaii. Formosan subterranean termites, *C. formosanus*, were collected using a trapping technique described by Tamashiro *et al.*[16] from three active field colonies on the Manoa campus of the University of Hawaii, designated as colonies A (near Gilmore Hall), B (near Pope Laboratory), and C (near Miller Hall). Because colonies of termites were available only on the island of Oahu, only a limited number could be transported to the island of Hawaii for this study. Thirty termite workers (pseudergates, or undifferentiated individuals older than the third instar) were placed in a Petri dish (diameter 100 mm, height 15 mm) provided with a moistened filter-paper disc. Three replicates were prepared from each of the three colonies for each interval of carbon dioxide exposure. The Petri dishes were placed into fumigation chambers, modified from 'Labconco'® desiccation chambers.[17]

To simulate commercial applications, where a constant gas flow would be impractical, fumigation chambers were filled with commercially obtained carbon dioxide from pressurized cylinders and sealed once a 100% concentration was detected, to minimize gas use. Carbon dioxide levels were monitored daily using a gas chromatograph equipped with a thermal conductivity detector. In order to maintain carbon dioxide concentrations $\geqq 95\%$ for the full time course of the experiment, a gas flow was allowed for approximately 2 h each day, or for a shorter interval if a 100% concentration was detected. This daily flush ensured that the carbon dioxide concentration constantly remained above 95% in all chambers. Control replicates were maintained in air-filled chambers. Termites were exposed to $\geqq 95\%$ carbon dioxide for 24, 48, 60, or 72 h. Temperatures throughout all study periods were $26(\pm 3)°C$

We also evaluated the effects of termite exposure to a 50% carbon dioxide atmosphere. Commercially obtained carbon dioxide and pressurized air were blended under constant pressure, with an accuracy of 10% of the target concentrations, and delivered to the treatment chambers (1-liter glass jars) as a constant flow. Three replicates of 30 termite workers from each of the three colonies were exposed to the 50% carbon dioxide atmosphere for 60 or 120 h at $26(\pm 3)°C$.

After exposure to a carbon dioxide atmosphere for the requisite interval, termites were held in Petri dishes with a moistened filter paper disc for 24 h in an unlighted incubator ($26(\pm 3)°C$), and mortality recorded. This was determined to be an appropriate interval in preliminary studies in which no additional mortality or recovery was observed in groups of termites held for several further days. Percentage mortality data were transformed by the arcsine of the square root and subjected to analysis of variance (ANOVA), and means separated by the Ryan–Einot–Gabriel–Welsch multiple F test, $P \leqq 0{\cdot}05$.[18]

2.2 Exposure to carbon dioxide under barrier conditions

Wooden 'barrier condition' experimental units were constructed to evaluate the efficacy of carbon dioxide fumigation against termites concealed within wood. Douglas-fir lumber was cut into blocks (90 mm × 90 mm × 152 mm) modeled after those used by Bess & Ota[1] in fumigant studies with *C. brevis*. A 36-mm hole was drilled to a depth of 114 mm in the center of each wooden block. Fifteen termite workers were placed in small stainless steel wire cages (35 mm × 20 mm), provisioned with a moistened piece of filter paper, closed with a No. 0 rubber stopper, and placed in the hole in the wooden block. A small (20 mm × 20 mm × 50 mm) piece of moistened sponge was inserted between the top of the wire cage and the top of the block to provide moisture during the trial. A wooden top (90 mm × 90 mm × 13 mm) was placed over the open end of the block and held in place by two screws positioned at opposite ends. Three replicates per treatment were prepared for each of the three termite colonies. The blocks were placed in fumigation chambers and exposed to a $\geqq 95\%$ carbon dioxide atmosphere for 48, 72, or 96 h at $26(\pm 3)°C$. After the treatment interval, termites were removed from the wire cages within the blocks and held in Petri dishes with a moistened filter paper disc for 24 h at 26°C. Mortality was analyzed as described above.

2.3 Effects on *Cryptotermes brevis*

Owing to difficulty in obtaining adequate numbers of West Indian drywood termites, nymphs from a single colony of *C. brevis* were included only in the 72-h barrier condition test. Three replicates of 15 nymphs each were placed within wooden blocks, exposed to $\geqq 95\%$ carbon dioxide, and termite mortality evaluated in the same manner as with *C. formosanus*.

3 RESULTS AND DISCUSSION

Although it is wise to consider intercolony differences in termite efficacy studies,[19] the three *C. formosanus* colonies included in our study exhibited relatively minor differences in their susceptibility to carbon dioxide. Colony C appeared to be slightly less tolerant to short exposure intervals than either of the other two colonies, although a 24-h exposure to a $\geqq 95\%$ carbon dioxide

atmosphere caused significant mortality (50–71%) in all three colonies (Table 1). However, a 60-h direct exposure was required to obtain 100% termite mortality.

Direct exposure of *C. formosanus* workers to a 50% carbon dioxide atmosphere for 60 h elicited significant (68–72%) but not complete mortality (Table 2). However, complete termite mortality was obtained after exposure to this lesser concentration of carbon dioxide for 120 h.

When termites were sealed within wooden blocks, a longer exposure to ≧ 95% carbon dioxide was necessary for complete control (Table 3). Although a 72-h exposure resulted in high mortality (87–93%), 96 h exposure was required for 100% mortality.

In our single trial with *C. brevis*, a 72-h exposure under these barrier conditions resulted in significant mortality (62·2(±7·7)%) in comparison to *C. brevis* control mortality of 8·9(±3·8)%, but less than that obtained with *C. formosanus*. Rust[11] found that a 72-h exposure to a nitrogen-modified atmosphere with less than 0·1% oxygen at an unstated ambient temperature was sufficient to kill another drywood termite species, *Incisitermes minor* (Hagen) nymphs, sealed in similar blocks. This apparent difference in susceptibility in two Kalotermitids, *C. brevis* and *I. minor*, may be partially attributable to different experimental conditions. However, it is also likely that interspecific physiological differences are involved, since there is evidence that exposure to carbon dioxide, as in our study, more rapidly impairs energy production[20] and would thus be expected to provide more rapid lethal action than the exposure to nitrogen used by Rust.[11]

Our results lend further support to the use of modified atmospheres to control insect infestation of commodities, wooden objects, and structures. Although a 72-h[11] to 96-h (Table 3) exposure period to atmospheres modified with nitrogen or carbon dioxide is longer than the exposure to a conventional fumigant required to kill termites concealed within wood,[21] concerns over undesirable residues or adverse reactions with treated commodities would be negligible.[10]

Exposure of wood infested by *C. formosanus* to a ≧ 95% carbon dioxide atmosphere for 96 h may only be possible in vault, or other small-scale, fumigations.

TABLE 1

Mortality of *Coptotermes formosanus* Workers 24 h after Exposure to a ≧ 95% Carbon Dioxide Atmosphere for Intervals of 24–72 h

Termite colony	*Termite mortality after exposure interval (%)[a] (±SD)*							
	24 h		*48 h*		*60 h*		*72 h*	
	CO_2	*Control*	CO_2	*Control*	CO_2	*Control*	CO_2	*Control*
A	71·1 (±1·3)a	1·1 (±1·5)b	95·6 (±1·5)ab	1·1 (±1·5)c	100 (±0)a	0 (±0)b	100 (±0)a	2·2 (±1·5)ab
B	56·7 (±11·1)a	0 (±0)b	82·2 (±14·8)b	1.1 (±1·5)c	100 (±0)a	0 (±0)b	100 (±0)a	4·4 (±1·5)b
C	50·0 (±14·5)a	1·1 (±1·5)b	100 (±0)a	1·1 (±1·5)c	100 (±0)a	0 (±0)b	100 (±0)a	6·7 (±2·2)b

[a] Each mean (±SD) represents three replicates of 30 workers each (untransformed). Means within each exposure interval followed by the same letter are not significantly different ($P \leqq 0.05$, ANOVA of transformed percentages, Ryan–Einot–Gabriel–Welsch multiple F test; df = 5, 12).

TABLE 2

Mortality of *Coptotermes formosanus* Workers 24 h after Exposure to a 50% Carbon Dioxide Atmosphere for Intervals of 60–120 h

Termite colony	*Termite mortality after exposure interval (%)[a] (±SD)*			
	60 h		*120 h*	
	CO_2	*Control*	CO_2	*Control*
A	72·2 (±3·7)a	1·1 (±1·5)b	100 (±0)a	3·3 (±2·2)b
B	67·8 (±3·7)a	3·3 (±2·2)b	100 (±0)a	2·2 (±1·5)b
C	68·9 (±5·2)a	0 (±0)b	100 (±0)a	3·3 (±2·2)b

[a] Each mean (±SD) represents three replicates of 30 workers each (untransformed). Means within each exposure interval followed by the same letter are not significantly different ($P \leqq 0.05$, ANOVA of transformed percentages, Ryan–Einot–Gabriel–Welsch multiple F test; df = 5, 12).

TABLE 3
Mortality of *Coptotermes formosanus* Workers Confined in Wooden Blocks 24 h after Exposure to a ≧ 95% Carbon Dioxide Atmosphere for Intervals of 48–96 h

Termite colony	*Termite mortality after exposure interval* (%)[a] (±*SD*)					
	48 h		*72 h*		*96 h*	
	CO_2	*Control*	CO_2	*Control*	CO_2	*Control*
A	55·6 (±3·0)b	2·2 (±3·0)c	93·3 (±0)a	2·2 (±2·2)b	100 (±0)a	4·4 (±3·0)b
B	57·8 (±11·9)b	4·4 (±3·0)b	91·9 (±3·0)a	4·4 (±3·0)b	100 (±0)a	6·7 (±4·4)b
C	82·2 (±7·7)a	0 (±0)c	86·7 (±0)a	8·9 (±3·0)b	100 (±0)a	6·7 (±6·7)b

[a] Each mean (±SD) represents three replicates of 15 workers each (untransformed). Means within each exposure interval followed by the same letter are not significantly different ($P \leq 0{\cdot}05$, ANOVA of transformed percentages, Ryan–Einot–Gabriel–Welsch multiple F test; df = 5, 12).

However, Keever[14] was able to maintain carbon dioxide concentrations of 35–60% in a large warehouse for seven days, killing all stages of the cigarette beetle, *Lasioderma serricorne* (F.). Since a five-day direct exposure to 50% carbon dioxide is lethal to *C. formosanus* (Table 2), our results suggest that the fumigation conditions maintained by Keever[14] might be sufficient to eradicate termites, as well as stored products pests, infesting the structure. Although our study did not address the relative costs of using carbon dioxide in comparison to conventional fumigants, these favorable biological results should stimulate such cost-benefit analyses.

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