RESPONSE OF SEVERAL SPECIES OF INSECTS TO MIXTURES OF PHOSPHINE AND CARBON DIOXIDE

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ABSTRACT

Exposure of several species of insects to low levels of phosphine (50 or 200 mL/L) in CO_2-air mixtures (25 or 75% CO_2) enables a quicker kill than does exposure to either CO_2-air mixtures or to phosphine in air. These species are *Tribolium castaneum*, *Tribolium confusum*, *Rhizopertha dominica* and *Trogoderma granarium*. This result is sometimes due to synergism - i.e. CO_2 potentiates the action of phosphine - and sometimes due to the relative order of susceptibilities of different insect stages to one component of the mixture. Under the conditions studied mixtures of phosphine and CO_2-air were not more effective at the LT_{99} level than phosphine alone in controlling pupae and eggs of *Sitophilus granarius* and *Sitophilus oryzae*.

INTRODUCTION

The temperate middle-European climate, while enabling insect control by aeration for much of the year, results in summer conditions that are too sultry for the use of aeration but cool enough (15-25°C) to require high concentration by time products for inert atmospheres or phosphine. It was in view of this background that we investigated the effects of mixtures of phosphine, carbon dioxide and air mixtures against adults, pupae, larvae and eggs of *Sitophilus granarius* (L.), *Sitophilus oryzae* (L.), *Tribolium castaneum* (Herbst), *Tribolium confusum* (duVal), *Rhizopertha dominica* (F.) and *Trogoderma granarium* (Everts) at the low temperature of 19°C and at 70% relative humidity. Insects were exposed to mixtures of gases for defined periods and then held at 25°C, 70% rh for end point mortality, in the case of adults, 3 weeks mortality, in the case of external larvae, complete transformation to the next stage, in the case of external eggs or pupae and complete emergence to adults in the case of internal stages of *Sitophilus* species and of *R. dominica*. A fuller account of the experimental procedure is given by Desmarchelier (1984).

RESULTS

The stages most resistant to 75% CO_2, 25% air were pupae of *Sitophilus* species, and *T. granarium* and larvae of *T. granarium*. Adults and pupae, but not eggs and larvae, of *S. granarius* were significantly more tolerant to CO_2 than corresponding stages of *S. oryzae*.

Table 1 - Time to mortality (LT_{50}) for stages of 6 species exposed to 75% CO_2, 25% air at 19°C, 70% rh.

Species	LT_{50} (h)			
	Adults	Pupae	Larvae	Eggs
Sitophilus granarius	63	207	68	56
Sitophilus oryzae	15	63	48	73
Tribolium castaneum	39	99	51	28
Tribolium confusum	45	75	47	15
Rhizopertha dominica	27	50	31	94
Trogoderma granarium	40	238	312	115

In studies on the effect of 25% CO_2, 75% air on the 4 stages of each of the six species studied, mortality after 7 days exposure was generally low, but 100% in the cases of eggs of *T. castaneum* and *T. confusum* and adults of *S. oryzae* and between 50 and 99% for adults and larvae of *R. dominica*.

Selected data on the toxicity of mixtures of CO_2, air and phosphine to *S. oryzae* and *S. granarium* is shown in Table 2. The data are similar for each species in that addition of CO_2 accelerates the speed of action of phosphine against adults and, to a lesser extent, against larvae, but does not accelerate the speed of action of phosphine against the stages most tolerant to phosphine, namely eggs and pupae.

Table 2 - Time to 50% mortality (LT_{50}) for stages of *S. oryzae* and *S. granarius* exposed to mixtures of carbon dioxide, air and phosphine at 19°C, 70% rh.

CO_2 in air (%, V/V)	PH_3 (mL/L)	Species	LT_{50} (h)			
			Adults	Pupae	Larvae	Eggs
75	0	S. oryzae	15	63	48	73
0	200	"	3.5	12	11 *	44
25	200	"	0.51	12	9 *	44
75	200	"	0.47	10	7 *	44
75	0	S. granarius	68	207	8 *	56
0	200	"	4.8	32	7.1 *	21
25	200	"	0.24	36	4.8 *	19
75	200	"	0.75	32	3.7	22

*Exposed to 50 mL/L phosphine

The position could, however, be different when one considers the addition of a small amount of phosphine, for example 50 mL/L, to a CO_2 fumigation. This amount is sufficient to kill the larvae - the LT_{99} values in 50 mL/L phosphine, 75% CO_2, 25% air are 34.3 and 14.4 h - respectively for larvae of *S. oryzae* and *S. granarius*. This amount of phosphine could be important in preventing control failures associated with e.g., the development of larvae into pupae during the experiment, or isolated cold spots where CO_2 is incompletely effective. The numerical preponderance of larvae vis-a-vis pupae or eggs merits consideration in this context.

Similarly use of 50 mL/L phosphine will control larvae of *R. dominica* (Table 3). Carbon dioxide accelerates the action of phosphine against larvae and adult stages.

Table 3 - Time to 50% mortality (LT_{50}) for stages of *Rhizopertha dominica* exposed to mixtures of carbon dioxide, air and phosphine at 19°C, 70% rh.

CO_2 in air (%, V/V)	PH_3 (mL/L)	LT_{50} (h) for:			
		Adults	Pupae	Larvae	Eggs
75	0	27	50	3.4	94
0	200	3.7	7.6	8.6*	8.3
25	200	1.7	3.3	5.6*	7.9
75	200	1.5	4.2	4.7*	8.1

*PH_3 concentrations were 50 mL/L for larvae

For *Trogoderma granarium* the LT_{99} values are presented graphically (Figure 1). Here the time to 99% kill in a mixture of 50 mL/L phosphine and 75% CO_2 is only approximately half the time required in CO_2 alone (cf. Table 1) or in phosphine alone. Under the conditions studied, carbon dioxide does not alter the sensitivity of phosphine to pupae but the time to 99% mortality of the phosphine-tolerant larvae decreases rapidly with increasing CO_2 content.

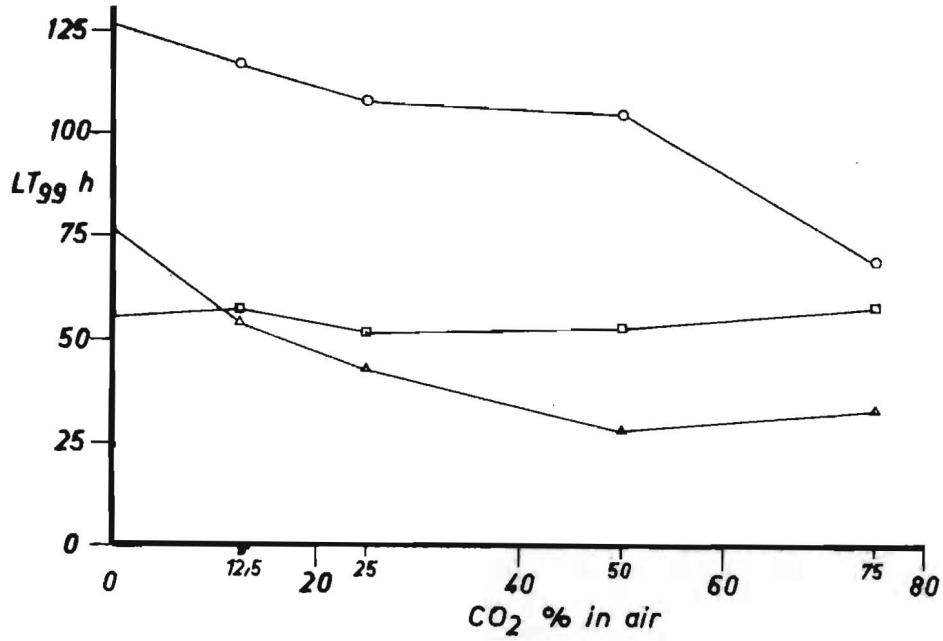

Figure 1 - Time to 99% mortality (LT_{99}) for adults (o), pupae (□) and larvae (Δ) of *Trogoderma granarium* exposed to 50 mL/L phosphine in CO_2-air mixtures, at 19°C, 70% rh.

Mixtures of carbon dioxide and phosphine result in a rapid kill of *Tribolium* species, due to synergistic effects between the two against larvae and adults, and to the sensitivity of pupae to phosphine, which is maintained in CO_2, and to the sensitivity of eggs to CO_2. Results for *T. castaneum* are given in Figure 2, together with results for adults of *T. confusum*. For this species, time to mortality decreases with CO_2 concentration over the range 0-75% CO_2, whereas for adults of *T. castaneum* the speed of kill is dependent on CO_2 concentration in the range 0-25%. Time to mortality for larvae of *T. castaneum* is also dependent on CO_2 concentration over the range tested, whereas CO_2 does not effect the toxicity of phosphine to pupae.

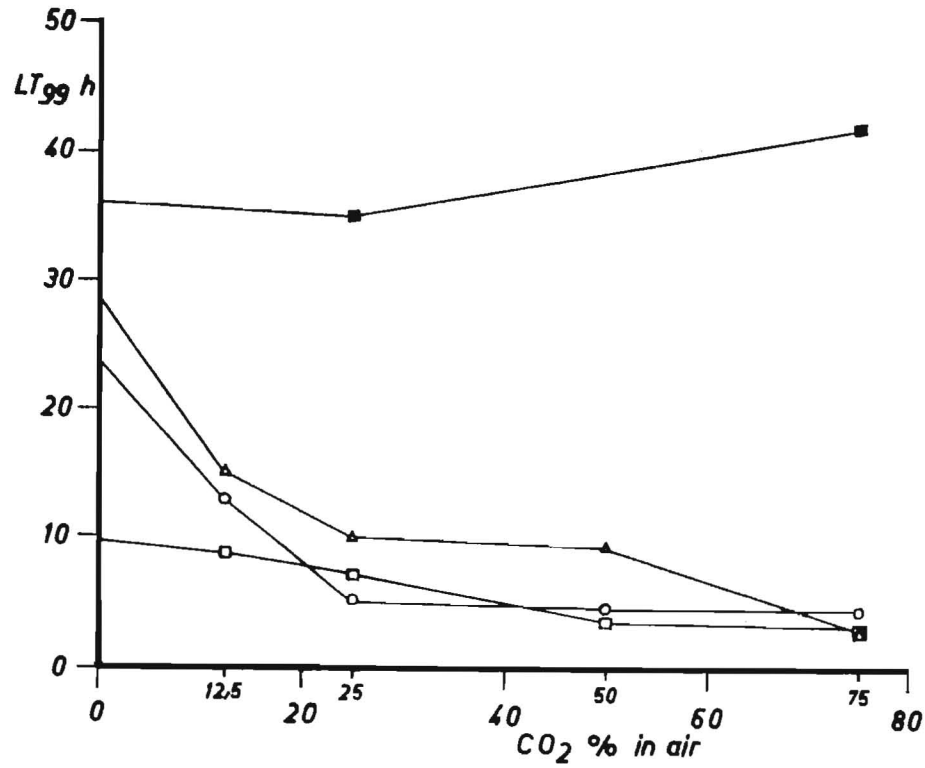

Figure 2 - Time to 99% mortality (LT_{99}) for adults of *Tribolium confusum* (▲) and adults (o), pupae (■) and larvae (□) of *T. castaneum* exposed to 50 mL/L phosphine in CO_2-air mixtures at 19°C, 70% rh (Results for *T. castaneum* adults were calculated as four times the measured value at 200 mL/L phosphine).

DISCUSSION

For *Tribolium* species, a mixture of 25% carbon dioxide and 50 mL/L phosphine offers a clear economic alternative to either high CO_2, or high phosphine, concentrations. A similar comment applies to mixtures of high CO_2 and low phosphine concentrations for the control of *T. granarium* and *R. dominica*. If similar values are confirmed for other species, especially moth species, the use of low phosphine, CO_2 air mixtures could find a use in disinfesting commodities where *Sitophilus* is not a problem. Such products include commodities with high oil content, such as cocoa and nut products, where high levels of phosphine can cause residue levels in excess of 0.1 mg/kg.

The use of low levels of phosphine to kill internal larvae in a CO_2 fumigation has been discussed. It should here be pointed out that the LT_{99}, but not the LT_{50}, of adults of *S. granarius* in 75% carbon dioxide, 25%

air, or in other gas mixtures containing 5% oxygen, is greater than the LT_{99} in air. However at 200 mL/L phosphine this protective effect of low O_2 levels is not observed.

In summary, there would seem to be a niche in stored products for mixtures of phosphine and carbon dioxide.

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