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Post-fumigation productivity of *Trogoderma granarium* Everts (Coleoptera: Dermestidae)

S. RAJENDRAN

Infestation Control and Pesticides Discipline, Central Food Technological Research Institute, Mysore-570 013, India

Abstract

The productivity of adults of *Trogoderma granarium* Everts was reduced following fumigation of the larvae with high dosages of carbon tetrachloride, ethylene dibromide or phosphine. Carbon dioxide, ethylene oxide, methyl bromide, methyl iodide and trichloroethylene had little influence on the productivity. From 0 to 23% of surviving larvae diapaused compared with 3% of untreated ones.

Introduction

In the chemical control of pests, the survivors following treatment are of special concern since they may become parent stocks for resistant strains. A study on the productivity of the survivors following fumigation is useful in addition to mortality data. The effect of fumigants on the productivity of *Callosobruchus chinensis* (L.), *Sitophilus oryzae* (L.) and *Tribolium castaneum* (Herbst) was reported earlier (Rajendran & Muthu, 1981).

The khapra beetle, *Trogoderma granarium* Everts, believed to be a native of India, has spread and become established in other parts of the world (Banks, 1977). The larva, the stage most often transported in commerce, survives adverse conditions like food shortage and extreme temperatures and humidity (Burges, 1962). They are tolerant of many insecticides and fumigants and often survive treatment (Lindgren et al., 1955; Hurlock, 1962). There are many factors that induce the larvae to enter diapause, including both density-dependent and density-independent ones (Nair & Desai, 1972). The results of a study on the productivity of adults of *T. granarium* that had been exposed as larvae to carbon tetrachloride, ethylene dibromide, ethylene oxide, methyl bromide, methyl iodide, trichloroethylene, phosphine or carbon dioxide are reported here.

Materials and methods

T. granarium cultures were maintained on broken wheat at 35°C and 40% RH under constant darkness in an incubator. Thirty larvae, 8–10 days old, were placed in petri dishes in each replicate. Based on trial experiments, five doses were selected for productivity studies for each fumigant and six replicates were carried out for each dose. The larvae were fumigated in 0·85-litre desiccators for 24 h at 26–30°C and 60–75% RH as described by Rajendran & Muthu (1981).

After exposure, the larvae from each replicate were transferred to plastic vials containing 20 g broken wheat. The vials were kept under the rearing condition of temperature and humidity. Fifteen days later and each week thereafter, adults which had emerged were counted and sexed. Simultaneously, the F_1 larvae were counted and discarded until no more were found. Larvae that failed to moult to the pupal stage within 45 days following treatment were recorded as diapausing, and no attempt was made to break the diapause for productivity studies. The final mortality was corrected

TABLE I. *The productivity of* T. granarium *adults that survived exposure to fumigants as larvae*

Fumigant	Dose (mg/litre)	Total numbers of			Corrected final mortality (%)	Productivity† (progeny produced/female) (mean ±s.e.)
		Diapausing larvae	Adults			
			♂♂	♀♀		
Ethylene dibromide	0·50	1	52	53	27·9	45·4 ±4·3*a*
	1·00	0	9	15	83·7	21·7 ±13·4*b*
	1·25	0	20	8	81·0	7·6 ±6·5*b*
	1·50	0	0	0	100	0
	1·75	0	0	0	100	0
Ethylene oxide	1·00	2	51	58	24·5	47·8 ±4·2*a*
	1·50	1	36	36	50·3	38·0 ±4·1*b***
	2·00	6	29	30	55·8	52·1 ±2·2*a*
	2·50	1	12	14	81·6	55·6 ±6·6*a*
	3·00	0	2	0	98·6	0
Methyl bromide	0·50	4	65	62	10·9	37·9 ±5·0*b***
	1·00	4	65	54	16·0	48·9 ±2·2*a*
	2·00	0	47	36	43·5	50·9 ±4·7*a*
	3·00	0	0	2	98·6	0
	4·00	0	0	0	100	0
Methyl iodide	0·13	7	63	73	0·7	46·4 ±1·9*a*
	0·25	3	58	62	16·3	48·9 ±3·3*a*
	0·50	5	44	62	24·5	47·1 ±4·5*a*
	1·00	6	39	42	40·8	43·4 ±3·9*a*
	2·00	1	20	17	74·2	31·6 ±9·0*a*
Phosphine	0·002	5	58	77	0·7	36·6 ±2·9*ab*
	0·004	3	67	68	2·1	40·6 ±2·5*ab*
	0·008	1	57	51	22·7	35·5 ±4·6*ab*
	0·016	4	33	47	40·4	28·1 ±11·9*b*
	0·024	2	30	36	51·8	18·8 ±8·5*b*
Carbon dioxide	8*	4	59	71	5·0	43·6 ±5·4*a*
	16*	0	75	59	5·0	51·1 ±4·8*a*
	32*	0	62	64	10·6	37·4 ±2·6*a*
	48*	3	40	42	39·7	35·0 ±6·5*a*
	64*	2	35	42	44·0	41·6 ±2·5*a*
Carbon tetrachloride	10	3	51	72	10·6	44·5 ±2·8*a*
	20	5	67	63	4·3	42·3 ±2·8*a*
	40	3	29	44	46·1	51·0 ±6·9*a*
	50	3	5	5	90·8	14·8 ±9·7*b*
	60	0	2	2	97·2	0
Trichloroethylene	5	4	72	80	0	38·2 ±3·0*a*
	10	4	64	72	0·7	35·6 ±2·5*a*
	20	1	65	59	11·3	39·9 ±2·0*a*
	40	3	26	23	63·1	44·5 ±11·4*a*
	60	3	8	9	85·8	28·3 ±11·9*a*
Control	—	9	138	141	(20·0)	46·0 ±2·3*a*

*The percentage of carbon dioxide.
†Mean of 12 replicates in control and 6 in treated. Means followed by different letters differ significantly ($P \leq 0{\cdot}05$) by Duncan's new multiple range test.
**Not significantly different from control (*ab*).

for control mortality. The productivity of the survivors (the number of progeny produced per female) was calculated together with its standard error. As the values followed a Poisson distribution, square root transformation was applied and then an analysis of variance was performed.

Results

The productivity of treated samples varied according to the fumigant and its dosage (Table I). Phosphine lowered the productivity of survivors at doses causing 40 and 52% mortality. With ethylene dibromide and carbon tetrachloride, the inhibitory effect was noted only above the LD80. Methyl bromide and ethylene oxide at 0·5 (LD11) and 1·5 (LD50) mg/litre, respectively, reduced the productivity, but the reduction was not significant. Productivity was unaffected in insects surviving exposure to methyl iodide, trichloroethylene and carbon dioxide. No treatment caused total inhibition of reproduction in survivors, nor was there any case of increased productivity.

Ethylene dibromide and phosphine were the most toxic fumigants, followed by methyl iodide and ethylene oxide; trichloroethylene was the least toxic apart from carbon dioxide. Among the total survivors, about 3% were the diapausing larvae in the controls and 0–23% in fumigated batches. In no case did more than 7 individuals (4%) diapause in treated batches and 5 in controls (3%) out of 180 insects tested.

Discussion

It is clear from these results that fumigants can influence the productivity of the survivors. Phosphine caused a significant reduction at doses causing 40 and 52% mortality. Winks (1971) observed an increase in productivity of adults of *Tribolium castaneum* that had been exposed as larvae to dosages of phosphine achieving some mortality. Nevertheless, at sublethal dosages, he noted the opposite effect. Adult survivors of larvae or pupae of *Sitophilus granarius* (L.) that were exposed to phosphine produced reduced numbers of progeny (Howe, 1973). In the present study, ethylene dibromide depressed the productivity of survivors of exposure at 1 and 1·25 mg/litre but had little effect at 0·5 mg/litre (LD28). Loschiavo (1960) noted reduced fecundity of *T. confusum* DuVal exposed to ethylene dibromide. The productivity of adults of *T. castaneum* and *S. oryzae* was decreased after fumigation with ethylene dibromide at the LD50 (Rajendran & Muthu, 1981). These authors also noted that whereas exposure to methyl iodide and carbon tetrachloride, either alone or mixed with acrylonitrile, had little effect on the productivity, exposure to trichloroethylene increased the numbers of progeny. In the present investigation, carbon tetrachloride decreased the productivity of *Trogoderma granarium* survivors only at the LD91 and LD97, whereas methyl iodide and trichloroethylene had no effect at all. The productivity was little affected by ethylene oxide and methyl bromide except at 1·5 (LD50) and 0·5 (LD11) mg/litre, respectively; but the inhibition was not significant when compared with the control. However, the fertility of adults of *Ephestia elutella* (Hübner) developing from diapausing larvae fumigated with methyl bromide was depressed (Bell, 1977). Rajendran & Muthu (1981) found that a dose of ethylene oxide achieving 50% kill markedly inhibited the productivity of adults of *Tribolium castaneum* and *S. oryzae*, but similar exposure to methyl bromide did not. They also found that carbon dioxide (50%) producing 32% mortality, affected the reproduction potential of *T. castaneum*. In the present study, carbon dioxide did not affect the productivity of *Trogoderma granarium* even at a concentration of 64%, the LD44; the higher tolerance of this insect to carbon dioxide may be one of the reasons.

In insects, egg production is under the control of the corpora allata hormone (and neurosecretions from the pars intercerebralis), the production of which is influenced by nutritional factors, mating, photoperiod, etc. (Engelmann, 1968). In the present investigation, any lowering of productivity is unlikely to have been mediated by the neuroendocrine system because only younger larvae were fumigated. Moreover, as the reproductive system in larvae is at a rudimentary stage of development, any damage could be repaired in the course of development to the adult stage. In fact, chemosterilisation has been shown to be unsuccessful when larvae were treated (LaChance et al., 1968). In contrast, Maheshwari & Sehgal (1977) found that fumigation of last instar larvae (of unknown age) with tepa limited the reproductive ability of both male and female adults.

In *T. granarium*, males emerge earlier than females (Burges, 1963), a single copulation is sufficient to fertilise all the eggs and virgin females live longer than fertilised ones (Hadaway, 1956). Delayed mating, however, results in reduced fecundity (Karnavar, 1972). Unsynchronised pupation resulting in unsynchronised emergence of male and female adults may be a reason for the decreased productivity of the fumigated insects. Hence, although two males and two females emerged following fumigation with carbon tetrachloride at 60 mg/litre, they did not emerge simultaneously, whereas at 50 mg/litre, eclosion of the five male and five female survivors was synchronised and viable progeny were produced. Differential sex susceptibility leading to selective elimination of one of the sexes is another limiting factor for the productivity of fumigated insects, but no such effect was demonstrated here. Punj & Verma (1970), however, noted that male pupae of *T. granarium* were more susceptible than female pupae to carbon disulfide, ethylene dibromide, ethylene oxide and methyl bromide.

An average of 13 to 61 eggs/female with more than 75% hatching has been reported in *T. granarium* (Shulov, 1955; Karnavar, 1973). The average number of larvae produced, in the present study, was 46·0 (range 34·8–61·3) per female in controls. After exposure to trichloroethylene at 40 mg/litre, 97 larvae were produced by a single female surviving with seven males in one replicate. At 60 mg/litre, one male and one female produced only 11 larvae.

About 100 mg of food (whole wheat flour plus 5% brewers' yeast or broken wheat alone) is sufficient for full development of a single *T. granarium* larva (Sharifi, 1958). It is interesting to note that in the present tests, a small percentage of diapausing larvae were recorded in fumigated as well as control batches even in the presence of surplus diet and optimal conditions of temperature and humidity. It is not known when the larvae entered diapause or whether pre-diapause development improves the chance of survival. Burges (1963) recorded that about 6·7% of the larvae entered diapause at lower population densities, and Nair & Desai (1972) recorded about 35% in isolated cultures at 30°C.

After phosphine, ethylene dibromide was the most toxic fumigant to the larvae of *T. granarium* as reported by other workers (Lindgren & Vincent, 1959; Punj & Girish, 1969). Punj (1970) noted that methyl bromide was more toxic than ethylene dibromide to the full grown (age not given) larvae based on mortality counts on the seventh day following fumigation. However, for ethylene dibromide, a period of at least 20 days is necessary for end-point mortality (Rajendran & Muthu, 1981).

To summarise, the productivity of adult survivors from larvae of *T. granarium* was significantly decreased only by high dosages of carbon tetrachloride, ethylene dibromide and phosphine. No fumigant completely suppressed productivity. Hence, the adults developing from any larvae of *T. granarium* surviving fumigation are likely to be able to breed, and only by maintaining lethal concentrations at all locales in fumigation systems for a sufficient period to kill all stages of the beetle can eradication be achieved.

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