

Efficacy of Sulfuryl Fluoride Against Four Beetle Pests of Museums (Coleoptera: Dermestidae, Anobiidae)

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ABSTRACT The efficacy of sulfuryl fluoride against adults, larvae, and eggs of four coleopterans—furniture carpet beetle, *Anthrenus flavipes* LeConte; black carpet beetle, *Attagenus megatoma* (F.); cigarette beetle, *Lastoderma serricornis* (F.); and hide beetle, *Dermestes maculatus* (De Geer)—was determined. Adults were generally more susceptible to sulfuryl fluoride than larvae. Eggs were the most tolerant stage; 7–30 times more fumigant was required compared with rates required to kill adults and larvae. Our results indicated that the cumulative dose required to kill 99% of *A. flavipes* larvae was 156 mg·h/liter. This rate exceeds the current recommended rate (approximately 72 mg·h/liter) of sulfuryl fluoride for control of carpet beetles. Eggs of cigarette beetles exposed to higher concentrations of sulfuryl fluoride developed at a slower rate. For multiple fumigation intended to control adults and larvae rather than eggs, the delayed embryonic development of eggs exposed to the sublethal dose of sulfuryl fluoride should be considered in determining the timing between fumigations.

KEY WORDS Insecta, Dermestidae, Anobiidae, museum pest control

CONTROL OF MUSEUM PESTS has been one of the major tasks for conservators because the damage inflicted to priceless museum artifacts is irreversible. A number of insect species pose a potential threat to a variety of museum articles (Story 1985). As early as the last century, Hagen (1881) recognized the black carpet beetle, *Attagenus megatoma* (F.), as a destructive museum invader. Back & Cotton (1938) reported a long list of animal and grain products being attacked by this dermestid.

Insecticidal sprays, dusts, or vapor boards (e.g., vinyl strips impregnated with dichlorvos) are commonly applied for control of museum pests. Such applications are ineffective against pests hidden inside a commodity and may be harmful to valuable museum articles. Fumigants can penetrate the thick barrier of most commodities. One of the commonly used fumigants, methyl bromide, is effective against dermestids (Pence & Morganroth 1962), but its potential for producing malodorous compounds and changing chemical composition with respect to dating and molecular biology in some animal products makes it undesirable for use in museums. Sulfuryl fluoride, which is a relatively inert compound, has little effect on materials that can be altered by methyl bromide (Kenaga 1957).

Interest in using sulfuryl fluoride for control of museum pests has been renewed. The potential of sulfuryl fluoride to affect priceless museum articles such as paintings is currently being investigated by the Getty Conservation Institute, the Smithsonian Institution, and the Canadian Conservation Institute. Little information, however, is available on

sulfuryl fluoride's efficacy against museum pests. Kenaga (1957) provided the only efficacy data of this fumigant against larvae and eggs of *A. megatoma* and adults of the cigarette beetle, *Lastoderma serricornis* (F.).

Our study was done to determine the efficacy of sulfuryl fluoride as a fumigant against three developmental stages of each of four beetle pests. In addition to *A. megatoma* and *L. serricornis*, the furniture carpet beetle, *Anthrenus flavipes* LeConte, and the hide beetle, *Dermestes maculatus* (De Geer), were tested. *A. flavipes* is a pest frequently found in museum insect collections and upholstered furniture (Ebeling 1978). *D. maculatus* is often used to deflesh delicate museum specimens (Case 1950), but it also damages taxidermic collections in natural history museums. *L. serricornis* is the major pest in herbaria (Story 1985).

Materials and Methods

Two carpet beetles, *A. megatoma* and *A. flavipes*, were obtained from the Entomology Department, University of California, Riverside, and maintained for >12 mo at $28 \pm 1^\circ\text{C}$ in glass jars (8 cm diameter, 17 cm high) containing chicken feathers and dry cat food. *D. maculatus* and *L. serricornis* were collected from the Florida State Museum, Gainesville, and maintained in the glass jars at $29 \pm 0.1^\circ\text{C}$ for 3 mo and $28 \pm 1^\circ\text{C}$ for 15 mo, respectively. *L. serricornis* was reared on whole wheat flour supplemented with 5% brewer's yeast (vol/vol). *D. maculatus* was provided with baked

Table 1. Concentration ranges of sulfuryl fluoride tested for three stages each of four beetle pests of museums

Stage	Concentration range (mg/liter) ^a			
	<i>A. flavipes</i>	<i>A. megatoma</i>	<i>L. serricornes</i>	<i>D. maculatus</i>
Egg	5-60	5-60	9-42	6-39
Larva	3.0-5.2	2.0-4.2	1.7-2.8	0.15-1.80
Adult	2.0-4.2	0.2-2.4	0.5-1.6	0.1-1.2

^a Twelve concentrations in arithmetic progression were used for each range.

chicken wings and plastic tubes (1 cm diameter, 7.5 cm high) filled with water and capped with cotton. As the populations of *D. maculatus* increased, cotton balls were placed in the jars for additional harborage.

All insects were placed in metal cages during fumigation. The cages consisted of circular canisters (6.0 cm diameter, 1.9 cm high) capped snugly with a cover 0.9 cm deep. A 6-cm² opening was made in the cover, and a 60-mesh metal screen was attached to allow free diffusion of fumigant. A piece of filter paper (4.25 cm diameter) was placed in the cage on which a small amount of dried beef and a thin layer of flour were placed for *D. maculatus* and *L. serricornes*, respectively. Chicken feathers and finely ground cat food were provided for *A. megatoma* and *A. flavipes* adults and larvae during and after fumigation. Eggs were placed on double-sided sticky tape attached to a microscope slide cover slip (Vincent & Lindgren 1972). For *D. maculatus* eggs, a piece of dried beef wrapped with cotton was attached to the center of the tape. In the absence of food, newly emerged *D. maculatus* larvae cannibalized the unhatched eggs. No medium was provided for eggs of other coleopterans because the sticky tape effectively trapped the emerging larvae (Vincent & Lindgren 1972).

At the time of testing, eggs were at least 48 h old; adults were 7-14 d old. Ages of larvae fumigated were 6-9 mo, 10-12 mo, 1 mo, and 2 mo for *A. flavipes*, *A. megatoma*, *L. serricornes*, and *D. maculatus*, respectively. Fifteen to 20 insects were prepared in each stage-species combination for exposure to 12 sulfuryl fluoride concentrations (plus one control) spaced in arithmetic progression between the ranges given in Table 1. Ranges chosen were based on preliminary test results which yielded concentrations providing partial mortality. Fumigation was done simultaneously for 22 h at 26.5 ± 0.5°C in 12 grease-sealed glass desiccator fumigatoria (9 liter) fitted with septa-mounted injection ports (Osbrink et al. 1987). Sulfuryl fluoride (99% commercial grade) was introduced to fumigatoria with gas-tight syringes of appropriate volume by the method of Osbrink et al. (1987), except that the sulfuryl fluoride was transferred from a freshly filled septa-fitted gas sample bag. Gas chromatographic analysis of sulfuryl fluoride in fumigatoria atmospheres by the method of Scheffrahn et al. (1987) indicated negligible fumigant loss over the 22-h exposure period.

After the fumigation, insects were held in the cages at 26.5 ± 0.5°C for observation. Counts were made daily until no further mortality occurred for adults and larvae, or until no additional eggs hatched. Data were analyzed by probit analysis (SAS Institute 1985).

Results and Discussion

Except for the hide beetle, adults were generally twice as susceptible to sulfuryl fluoride as the larvae at LC₅₀ (Table 2). Because the mobile adults require greater gaseous exchange (Chapman 1971), they may have respired more fumigant. *D. maculatus* adults and larvae may have been equally susceptible to sulfuryl fluoride, mainly because both stages

Table 2. Comparative toxicity of sulfuryl fluoride (mg/liter) against three stages each of four beetle pest species of museums^a

Species	Stage	n ^b	Slope ± SE	LC ₅₀ (95% CL)	LC ₉₉ (95% CL)	Period after fumigation (d) ^c
<i>A. flavipes</i>	Egg	228	0.10 ± 0.01	15.97 (13.15-18.44)	38.80 (33.79-47.25)	18
	Larva	228	0.83 ± 0.13	4.30 (4.09-4.54)	7.11 (6.36-8.52)	8
	Adult	228	1.86 ± 0.28	2.30 (2.12-2.43)	3.55 (3.30-4.01)	6
<i>A. megatoma</i>	Egg	164	0.05 ± 0.007	29.93 (25.28-34.48)	77.00 (66.04-96.05)	18
	Larva	240	2.58 ± 0.45	2.19 (2.03-2.30)	3.09 (2.89-3.49)	2
	Adult	228	1.94 ± 0.24	0.79 (0.66-0.90)	1.98 (1.75-2.36)	4
<i>L. serricornes</i>	Egg	231	0.15 ± 0.02	16.90 (15.11-18.50)	32.35 (29.20-37.37)	8-10
	Larva	240	3.28 ± 0.50	1.83 (1.73-1.90)	2.54 (2.40-2.79)	3
	Adult	240	3.27 ± 0.38	0.88 (0.81-0.94)	1.59 (1.46-1.79)	3
<i>D. maculatus</i>	Egg	198	0.15 ± 0.02	19.12 (17.36-20.78)	34.93 (31.71-39.92)	5
	Larva	240	3.86 ± 0.47	0.67 (0.60-0.74)	1.27 (1.14-1.47)	6
	Adult	228	3.76 ± 0.53	0.68 (0.59-0.77)	1.30 (1.14-1.60)	3

^a Insects were fumigated at 26.5 ± 0.5°C for 22 h.

^b Number of insects tested excluding control.

^c Time after fumigation when no further mortality caused by sulfuryl fluoride exposure occurred for adults and larvae, or when no egg hatching was observed.

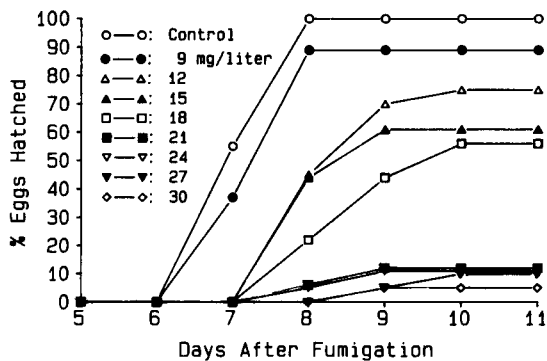


Fig. 1. Emergence rate (%) of *L. serricornis* eggs exposed to sulfuranyl fluoride at $26.5 \pm 0.5^\circ\text{C}$ for 22 h. No hatch was observed above 30 mg/liter.

of this beetle are similarly active. The egg stage is most tolerant to fumigants (Kenaga 1953, 1957) as a result of impermeability and uptake of fumigant by epiembryonic tissues, especially the chorion (Outram 1967). Our results showed that 7–30 times (at LC_{50}) more sulfuranyl fluoride was required to kill eggs compared with adult or larval stages.

Our LC_{50} for *A. megatoma* eggs (29.9 mg/liter for 22 h, or 657.8 mg·h/liter cumulative dose) was fairly comparable with Kenaga's (1957) results (42.3 mg/liter for 16 h, or 676.8 mg·h/liter). The cumulative dose required to kill 50% *A. megatoma* larvae (48.2 mg·h/liter) was higher than Kenaga's (1957) data (33.8 mg·h/liter). Cigarette beetle adults also were more susceptible in Kenaga's study than in ours (11.4 versus 19.4 mg·h/liter).

The two carpet beetle species were generally more difficult to kill by sulfuranyl fluoride than cigarette beetles. The hide beetle was the most susceptible species, probably because it is the most mobile and thus absorbed more fumigant than others. *A. megatoma* eggs were approximately twice as tolerant to sulfuranyl fluoride as the egg stage of *A. flavipes*. However, *A. megatoma* adults and larvae were almost two times more susceptible than those of *A. flavipes* (Table 2). Based on the larval LC_{95} of *A. megatoma* (38.2 mg·h/liter) reported by Kenaga (1957), the current recommended rate of sulfuranyl fluoride is 6 mg/liter for 20 h of fumigation (assuming 12 h half-loss time) at 27°C for all carpet beetles (Dow Chemical 1988). This prescribed rate (equivalent to 72 mg·h/liter), however, is below our LC_{99} (7.1 mg/liter, or 156.2 mg·h/liter) for *A. flavipes* larvae; thus it will not successfully control infestations of the furniture carpet beetle (Table 2).

The sulfuranyl fluoride label does not promote control of egg stages of carpet beetles. Instead, it recommends multiple fumigations. The first fumigation is intended to kill the existing adults and larvae, whereas the subsequent fumigation(s) is applied when the next generation is in its larval or adult stages. The LC_{99} for *A. megatoma* eggs was 77.0 mg/liter or 1,694 mg·h/liter (Table 2), which ex-

ceeded the 10× rate (10 times the drywood termite rate or equivalent to approximately 1,200 mg·h/liter) prescribed for control of powderpost beetle (Lyctidae) eggs (Dow Chemical 1988). If the ovidical effect of sulfuranyl fluoride is intended for carpet beetles, a 15–20× rate should be used.

Two to eight days were required for sulfuranyl fluoride to fully express its effects on adults and larvae of tested beetles (Table 2). Although there was little difference in the incubation period between fumigated and control eggs for *A. megatoma*, *A. flavipes*, and *D. maculatus*, eggs of *L. serricornis* exposed to sulfuranyl fluoride developed at a slower rate (Fig. 1). The time required for embryonic development was dependent on fumigant concentration. Because the multiple fumigation practice is designed to kill larva or adult insects, timing between fumigations is critical. The delayed hatching of *L. serricornis* as shown in our study should be considered in determining the timing between fumigations.

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