Evaluation of Esfenvalerate Aerosol for Control of Stored Product Insect Pests[1, 2]

Frank H. Arthur and Hagen B. Gillenwater

Stored-Product Insects Research and Development Laboratory, USDA-ARS, P.O. Box 22909
Savannah, GA 31403

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ABSTRACT An aerosol containing 0.25% AI esfenvalerate, 1.25% piperonyl butoxide synergist, 18.50% oil solvent and 80.00% freon was tested against adults of some of the major insect pest species infesting stored peanuts and stored tobacco. Application at 0.03 g AI per 28.3 m^3 killed at least 99% of the almond moths, *Cadra cautella* (Walker), Indianmeal moths, *Plodia interpunctella* (Hübner), and tobacco moths, *Ephestia elutella* (Hübner). Red flour beetle, *Tribolium castaneum* (Herbst) mortality was 100% at application rates of 0.03 and 0.05 g per 28.3 m^3. This was the least susceptible beetle species that was tested. Red flour beetles were knocked down at a rate of 0.013 g per 28.3 m^3, and a second application of the same rate killed all survivors. The biological effectiveness of esfenvalerate compares favorably with dichlorvos, which is currently used as an aerosol control in peanut and tobacco storages.

KEY WORDS aerosol, esfenvalerate, *Cadra cautella, Plodia interpunctella, Tribolium castaneum,* peanuts, tobacco, storage

After peanuts are harvested in the fall, they may be stored for up to 10 months in large commercial warehouses. The primary insect pests of stored peanuts are the almond moth, *Cadra cautella* (Walker); the Indianmeal moth, *Plodia interpunctella* (Hübner); and the red flour beetle, *Tribolium castaneum* (Herbst). Moth infestations are usually concentrated on the surface of the peanuts, while red flour beetles can be found on the surface and downward through the peanut stack. Surface infestations are controlled using dichlorvos aerosol, which will kill adult moths in the warehouse headspace and moth larvae and red flour beetles exposed on the peanut surface. The labelled rate for dichlorvos is 0.5 to 2.0 g AI per 28.3 m^3 (1,000 ft^3) of headspace.

When dichlorvos was first registered for stored peanuts, it was extremely toxic to all three pest species (Zettler 1982), but now almond moth and Indianmeal moth populations (Arthur et al. 1988) and red flour beetle populations (Halliday et al. 1988) in the southeastern United States are developing resistance to dichlorvos. The only labelled alternative aerosol treatment is synergised pyrethrins, but the source of natural pyrethrum is limited and formulated material is often unavailable. Currently there is no indication that dichlorvos resistance is causing control failures, but additional chemical insecticides that can be used in peanut warehouses should be developed and labelled before dichlorvos resistance levels increase.

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[2] This paper reports the results of research only. Mention of a pesticide or a commercial or proprietary product does not constitute a recommendation or endorsement by the U.S. Department of Agriculture.

Dichlorvos aerosols are also used in tobacco warehouses to control insect pests, particularly cigarette beetle, *Lasioderma serricorne* (F.), and tobacco moth, *Ephestia elutella* (Hübner). Dichlorvos is being reviewed by the Environmental Protection Agency, and if it were removed from the market, insect infestations in tobacco and peanut storage facilities would likely increase and cause significant economic damage. Therefore, there is an urgent need to develop an insecticide that could replace dichlorvos.

The pyrethroid insecticide fenvalerate, cyano(3-phenoxyphenyl) methyl 4-chloro-(1methylethyl)benzeneacetate, is labelled for a variety of vegetable, fruit, and ornamental crops. Fenvalerate aerosols have not been extensively tested against stored product insects. Kirkpatrick and Gillenwater (1979) found that fenvalerate applied at the rate of 1 g per 28.3 m^3 killed 45% of exposed adult confused flour beetle, *Tribolium confusum* (DuVal). However, these insects were exposed to the insecticide for only 30 minutes. In a later test (Halliday et al. 1987), fenvalerate aerosol applied at the rate of 0.025 g AI per 28.3 m^3 gave 91 and 100% knockdown of black carpet beetle larvae, *Attagenus unicolor* (Brahm), and adult confused flour beetle, respectively, but mortality for each species was only 24 and 31 % respectively. Bry et al. (1985) showed that direct application of 0.028 g AI fenvalerate spray protected woolen cloth against feeding damage from fabric insect pests.

Aerosols containing the S isomer of fenvalerate, esfenvalerate, were obtained from MGK Company (Minneapolis, MN). The objectives of our test were: 1) to determine the minimum dosage of esfenvalerate required to control insect pests in stored peanuts and stored tobacco; and 2) to determine the frequency of application necesary for complete control.

Materials and Methods

A series of trials were conducted in four test chambers at the USDA Stored-Product Insects Research and Development Laboratory, Savannah GA. Each chamber measured 42.5 m^3 and had a 0.093 m^3 removable glass panel in the entry door. Esfenvalerate aerosols were tested against the following insect species: almond moth, Indianmeal moth, tobacco moth, sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.) confused flour beetle, red flour beetle, drugstore beetle, *Stegobium paniceum* (L.), and cigarette beetle. The insects were obtained from pesticide susceptible colonies maintained at the laboratory.

Experiment 1. An esfenvalerate aerosol containing 49.375% dichlorodifluoromethane (F11), 49.375% trichlorofluoromethane (F12), and 0.25% AI esfenvalerate was evaluated in the first trial. After the floors of the four exposure chambers were lined with 40-lb Kraft paper, 50 adult almond moths and 50 adult Indianmeal moths were released into each chamber. Ten adult sawtoothed grain beetles, 10 adult confused flour beetles, or 10 adult red flour beetles were placed in each of nine separate 100 by 15 mm Petri dishes lined with filter paper. Glass cylinders 75 mm dia. and 25 mm in ht. coated with teflon were used to confine the sawtoothed grain beetles in the Petri dishes. A dish of each beetle species was placed 30 cm from each corner, 30 cm from the center of the four walls, and directly in the center of the chambers (27 total dishes in each chamber). Three of the chambers were used for the insecticide treatment and the other chamber was used for an untreated control. The aerosols were applied by removing the glass entry panel in the door and spraying the aerosol directly into the chamber for 4 sec. This gave an application rate of 0.01g AI/28.3 m^3, which was verified by weighing the aerosol cans before and after application. Aerosols were applied in late afternoon, and the insects were exposed until the following morning (14 hrs). Before the insects were removed, the chambers were force ventilated to provide three air exchanges. The moths were collected using a modified aspirator and then placed in 0.95-L jars. Beetles were removed from the chamber and placed in fresh Petri dishes. Knockdown for all species was recorded at 0 hrs post-exposure; almond moth, Indianmeal moth, and sawtoothed grain beetle mortality was assessed at 24 hrs; confused flour beetle and red flour beetle knockdown was recorded at 24 and 48 hrs, and mortality for the latter two species was assessed at 174 hrs. During the observation period insects were held in a laboratory room (25 ± 1° C, 80 ± 5% RH).

Two additional rates, 0.03 and 0.05 g AI/28.3 m^3, were tested, and each application rate was replicated three times. Before each replicate the old Kraft paper was discarded and the floors were lined with fresh paper. Insects were placed in the chamber and collected and held as previously described. Aerosols were applied as previously described, using a different chamber as a control room for each application rate.

Experiment 2. An aerosol containing 40% F11, 40% F12, 18.50% oil solvent, 1.25% piperonyl butoxide, and 0.25% esfenvalerate was tested against the same five insect species. The purpose of this experiment was to determine if the addition of the synergist and oil solvent would improve formulation toxicity. The chambers and the insect species were prepared as described for experiment 1, with the exception that an additional set of red flour beetles was placed in each chamber (36 total dishes in each chamber). Aerosols were applied at .01, .03, and .05 g AI/28.3 m^3. After the 14 hr exposure period all beetles except those red flour beetles in the extra set of Petri dishes were transferred to new dishes. The remaining set of red flour beetles were kept in their original dishes. Knockdown and mortality was recorded as described for Experiment 1, with the exception that knockdown for sawtoothed grain beetles was recorded at 0 and 24 hrs, and mortality was assessed at 48 hrs. Each application rate was replicated 3 times using a different room for the untreated control at each rate.

Experiment 3. The formulation described for Experiment 2 was used in this trial and all succeeding trials. Drugstore beetles, cigarette beetles, red flour beetles, and tobacco moths were tested along with the red flour beetle. A single application rate, 0.02 g AI/28.3 m^3, was replicated three times. Fifty adult moths were released into each room, and 10 beetles of each species were placed in separate dishes. All conditions were as previously described, with the exception that after the beetles were removed from the exposure chambers they were not transferred to new Petri dishes. Tobacco moth knockdown and mortality was assessed at 0 and 24 hrs, respectively. Knockdown for all three beetle species was recorded at 0, 24, and 48 hrs, and mortality was assessed at 174 hrs.

Experiment 4. In this trial, the red flour beetle was the only test species. Four Petri dishes containing 10 red flour beetles each were placed at each of the nine positions in the four chambers (36 total in each chamber). Four applications of esfenvalerate were applied into each chamber at the rate of 0.013 g AI/28.3 m^3. One chamber was treated every day, another chamber was treated every 2nd day, and the third chamber was treated every 3rd day. The day after each application a container of insects was removed from each position in each chamber, and the insects were kept in the same dish throughout the 174 hr observation period. Each test procedure was replicated three times.

Data from all four experiments were analysed using the GLM Procedure of the Statistical Analysis System (SAS Institute 1987).

Results

Experiment 1. At application rates of 0.03 and 0.05 g AI per 28.3 m^3, all confused flour beetles and red flour beetles were knocked down when they were removed from the exposure chamber (Table 1). However, nearly all of the affected individuals gradually recovered after they were transferred to new Petri dishes. After 48 hours red flour beetle knockdown was less than confused flour beetle knockdown, but mortality for both species was less than 10% at all three rates. Knockdown and recovery for sawtoothed grain beetle was similar to the results for the other two beetle species. All three application rates were effective against adult almond moths and Indianmeal moths; knockdown and mortality was nearly 100%.

Experiment 2. Adding the synergist and the oil solvent increased formulation toxicity; confused flour beetle and red flour beetle knockdown was 100% at all three rates (Table 2). When the insects were transferred to new Pettri dishes, fewer individuals recovered from knockdown, as compared to Experiment 1. Confused flour beetle and red flour beetle mortality at 0.05 g was 64 and 48%, respectively. Sawtoothed grain beetle mortality was 100% at 0.03 ad 0.05 g, and almond moth and Indianmeal moth mortality was less than 99% only at 0.01 g. The red flour beetle was the least susceptible species of those tested, but when they were held in their original Petri dishes after they were removed from the exposure chamber, no individuals recovered from knockdown at rates of 0.03 and 0.05 g.

Experiment 3. When a rate of 0.02 g AI per 28.3 m^3 was used against the red flour beetle and the tobacco insects, the red flour beetle was still the least susceptible species (Table 3). Initial knockdown was 100%, but red flour beetle recovery and survival was greater than recovery and survival for any other species. Mortality for tobacco moth, drugstore beetle, cigarette beetle, and red flour beetle was 100, 92, 83, and 59%, respectively.

Experiment 4. When esfenvalerate was applied at the rate of 0.013 g AI per 28.3 m^3, the initial red flour beetle knockdown was at least 97% after the first application for each spray schedule (Table 4). Mortality was 61 to 71%. However, the second application killed all insects that survived the first application, regardless of whether esfenvalerate was applied every day, every second day, or every third day.

Discussion

The results of our tests show esfenvalerate could replace dichlorvos as an aerosol treatment in peanut and tobacco storages. The lowest rate tested, 0.01 g AI per 28.3 m^3, killed nearly 100% of the adult almond moths and Indianmeal moths released into the test chambers. Adding the piperonyl butoxide synergist increased esfenvalerate toxicity. The red flour beetle was the least susceptible species of those that were tested, and an application rate that would control this

Table 1. Percentage knockdown (KD) and mortality (M) (mean ± SEM), of confused flour beetle (CFB), red flour beetle (RFB), sawtoothed grain beetle (STGB), almond moth (AM), and Indianmeal moth (IMM) exposed to three rates of esfenvalerate aerosol (per 28.3m³). Formulation contents: 49.375% F11, 49.375% F12, 0.25% esfenvalerate.

Species	Rate (g)	0 Hr KD	24 Hr KD	48 Hr KD	174 Hr M
CFB	.01	* 99.6 ± 0.4a	90.8 ± 3.8a	46.7 ± 4.4a	1.5 ± 0.7a
RFB		90.7 ± 3.0b	12.7 ± 5.2c	.4 ± 0.4b	2.1 ± 0.9a
STGB		88.9 ± 2.4b	† 27.5 ± 2.6b		
AM		98.7 ± 1.3a	† 98.7 ± 0.7a		
IMM		98.7 ± 1.3a	98.7 ± 1.3a		
CFB	.03	100.0 ± 0.0a	100.0 ± 0.0a	96.0 ± 1.4a	6.7 ± 1.3a
RFB		100.0 ± 0.0a	88.2 ± 3.6b	6.7 ± 1.6b	6.3 ± 1.6a
STGB		100.0 ± 0.4a	70.1 ± 3.7b		
AM		93.7 ± 3.0a	† 97.3 ± 0.7a		
IMM		99.7 ± 0.7a	† 98.0 ± 1.1a		
CFB	.05	100.0 ± 0.0a	100.0 ± 0.0a	96.9 ± 2.1a	9.1 ± 2.7a
RFB		100.0 ± 0.0a	99.2 ± 0.5a	28.3 ± 5.0b	3.3 ± 1.1b
STGB		100.0 ± 0.0a	85.2 ± 3.2b		
AM		100.0 ± 0.0a	† 100.0 ± 0.0a		
IMM		100.0 ± 0.0a	† 100.0 ± 0.0a		

* Means within columns followed by the same letter are not significantly different (P = 0.05), Duncan's Multiple Range Test [Proc GLM, SAS Institute]).
† KD and M are the same.

Table 2. Percentage knockdown (KD) and mortality (M) (mean ± SEM), of confused flour beetle (CFB), red flour beetle (RFB), sawtoothed grain beetle (STGB), almond moth (AM), and Indianmeal moth (IMM) exposed to three rates of esfenvalerate aerosol (per 28.3m³). Formulation contents: 40.00% F11, 40.00% F12, 18.50% oil solvent 1.25% piperonyl butoxide, and 0.25% esfenvalerate.

Species	Rate (g)	0 Hr K	D 24 Hr KD	48 Hr KD	174 Hr M
CFB	.01	*100.0 ± 0.0a	95.2 ± 2.9a	52.0 ± 7.8a	1.5 ± 0.7b
RFB1		100.0 ± 0.0a	39.7 ± 4.8b	9.2 ± 2.9b	2.2 ± 1.2b
RFB2†		89.7 ± 5.5a	66.4 ± 7.3b	66.4 ± 7.3a	37.2 ± 7.3a
STGB		96.6 ± 2.0a	67.4 ± 6.7b	51.7 ± 4.5a	
AM		87.7 ± 7.0a	‡ 94.0 ± 2.3a		
IMM		94.8 ± 2.7a	‡ 96.9 ± 2.1a		
CFB	.03	100.0 ± 0.0a	100.0 ± 0.0a	99.7 ± 0.4a	28.2 ± 5.1b
RFB*		100.0 ± 0.0a	71.1 ± 0.0b	19.9 ± 4.1c	9.3 ± 1.5c
RFB2†		100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a
STGB		100.0 ± 0.0a	98.2 ± 0.0a	84.4 ± 2.4b	
AM		97.3 ± 1.3a	‡ 99.3 ± 0.7a		
IMM		99.3 ± 0.7a	‡ 100.0 ± 0.0a		
CFB	.05	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	64.4 ± 6.1b
RFB1		100.0 ± 0.0a	100.0 ± 0.0a	86.3 ± 4.5b	48.0 ± 3.5c
RFB2†		100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a
STGB		100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	
AM		97.3 ± 1.8a	‡ 100.0 ± 0.0a		
IMM		99.3 ± 0.7a	‡ 100.0 ± 0.0a		

* Means within columns followed by the same letter are not significantly different (P = 0.05; DMRT).
† Red flour beetles held in their original exposed Petri dishes.
‡ KD and M are the same.

Table 3. Percentage knockdown (KD) and mortality (M) (mean ± SEM), of cigarette beetle (CB), drugstore beetle (DB), red flour beetle (RFB), and tobacco moth (TM) exposed to 0.02 g AI per 28.3 m^3 esfenvalerate aerosol. Formulation contents same as Table 2.

Species	0 Hr KD	24 Hr K	48 Hr KD	72 Hr KD	174 Hr M
CB	*100.0 ± 0.0a	98.6 ± 0.9a	94.1 ± 2.2a	89.9 ± 3.1a	82.9 ± 3.6b
DB	100.0 ± 0.0a	100.0 ± 0.0a	99.2 ± 0.5a	98.1 ± 1.2a	98.5 ± 0.9a
RFB	100.0 ± 0.0a	98.9 ± 1.1a	83.2 ± 5.0b	76.5 ± 6.4b	59.0 ± 5.9c
TM	100.0 ± 0.0a	† 100.0 ± 0.0a			

9* Means within columns followed by the same letter are not significantly different (P = 0.05, DMRT).
† KD and M are the same.

Table 4. Percentage knockdown (KD) and mortality (M) (mean ± SEM), of red flour beetles exposed to 0.0124 g AI esfenvalerate per 28.3m^3 applied every day, every other day, or every third day (4 applications total). Formulation contents same as Table 2.

Number	0 Hr KD	24 Hr KD	48 Hr KD	72 Hr KD	174 Hr M
		Daily Application			
1	* 98.8 ± 1.1a	91.7 ± 2.4b	76.3 ± 4.4b	60.7 ± 5.7b	70.8 ± 3.7b
2	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	98.8 ± 0.6a	100.0 ± 0.0a
3	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a
4	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a
		Application Every 2 Days			
Number	0 Hr KD	24 Hr KD	48 Hr KD	72 Hr KD	174 Hr M
1	96.2 ± 2.3a	82.9 ± 5.3b	70.6 ± 6.5b	64.7 ± 6.5b	60.8 ± 5.5a
2	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a
3	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a
4	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a
		Application Every 3 Days			
Number	0 Hr KD	24 Hr KD	48 Hr KD	72 Hr KD	174 Hr M
1	99.6 ± 0.4a	82.9 ± 5.5b	72.0 ± 6.5b	67.5 ± 6.7b	70.8 ± 5.9a
2	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a
3	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a
4	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a	100.0 ± 0.0a

* Means within columns followed by the same letter are not significantly different (P = 0.05, DMRT).

species would probably control the major insect pests in peanut warehouses and tobacco storages.

In experiment number 2, all red flour beetles that were exposed to 0.03 and 0.05 g AI per 28.3 m^3 were knocked down, but 174 h after beetles were transferred to new Petri dishes, mortality was only 9 and 41%, respectively. However, no affected individuals recovered from knockdown when they were kept in their original exposed dishes. This indicates that the low rates of esfenvalerate tested in our study could be effective on surface infestations under field conditions, because when insecticides are applied in the field, insects that are knocked down tend to remain in place and be exposed to the chemical residue.

The dichlorvos aerosol systems used in peanut warehouses in the southeastern United States are linked to a timing device, and are usually activated daily during the storage period. This is necessary because moth populations in peanut warehouses breed continuously throughout the year and do not have discreet generations (Hagstrum and Stanley 1979, Redlinger and Davis 1982). Our test indicates that daily esfenvalerate application at 0.01 to 0.03 g AI per 28.3 m^3 would control insect pests in peanut and tobacco warehouses. The effective application rate of esfenvalerate is considerably lower than the labelled rate for dichlorvos, which is 0.5 to 2 g per 28.3 m^3. Esfenvalerate is also less hazardous than dichlorvos; the oral and dermal LD50 in rats is 431 and >5.000 mg/kg and 56 and 75 mg/kg for esfenvalerate and dichlorvos, respectively. Esfenvalerate would be an important addition to pest management programs in peanut and tobacco storage facilities. Additional research will be conducted on esfenvalerate residue accumulation on peanuts and flue-cured tobacco during a simulated storage season.

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