Method for increasing the residual efficacy of insecticides on the cigarette beetle, *Lasioderma serricorne* (F.) (Coleoptera: Anobiidae) using adult settling behavior

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Abstract
Most cigarette beetle adults (*Lasioderma serricorne*) readily get into pipe rows of corrugated paper, and then settle there for a long time. Therefore, an insecticide application technique that takes advantage of this behavior was evaluated in the laboratory. Four strips of corrugated paper (23 cm in length, 2 cm in width) treated with the insecticides were arranged in a square on the floor of an insect cage (35 cm×35 cm, 50 cm in height), and then the insect adults were released. Residual efficacies of the corrugated papers treated with chlorpyrifos-methyl, pirimiphos-methyl, and fenitrothion (dosage: 125 mg AI/m²) on the insect adults consistently achieved almost 100% mortality. The minimum AI dosages which achieved more than 90% mortality after 4-months storage under conditions of 27°C and 60% RH were in 250 mg AI/m² of chlorpyrifos-methyl, 500 mg AI/m² of pirimiphos-methyl and 1,000 mg AI/m² of fenitrothion. The corrugated paper treated with these three insecticides showed no repellency to the insect adults immediately after treatment. These results suggest that corrugated paper treated with these insecticides would provide an excellent residual efficacy on the cigarette beetle adults. In contrast, corrugated paper treated with permethrin showed a low mortality of, and high repellency to, the insect adults.

Key words: *Lasioderma serricorne*; cigarette beetle; insecticide; residual efficacy; behavior

INTRODUCTION

The cigarette beetle, *Lasioderma serricorne* (F.) (Coleoptera: Anobiidae) is widely distributed throughout the world, and is one of the most serious pests of cured tobacco leaves, and grain meals. It infests these commodities during storage and manufacture, and at retail outlets as well.

Surface treatment is performed to control insects resting or crawling on surfaces by applying insecticides directly to a surface. Under actual field conditions, it is important to kill insects within a very short contact time, such as while they are walking on a surface zone treated with an insecticide before reaching the stored product. Otherwise, they will survive and move to infect and oviposit in the stored product. It is well known that the residual efficacy of insecticides on different material surfaces against insect adults varies significantly (Chadwick, 1985; Collins et al., 2000). However, there has been no investigation on the residual efficacy to the cigarette beetle.

The toxicities and the properties of some insecticides to cigarette beetle adults were evaluated using several methods (Benezet et al., 1986; Orui, 1993). It was found by the filter paper diffusion method that the residual contact efficacy of chlorpyrifos-methyl and fenitrothion (dosage: 250 mg AI/m²) had a very high mortality of, and no repellency to, the insect adult (Orui, 1993). Meanwhile, we often observe cigarette beetle adults settling in the pipe rows of corrugated paper for an extended time after getting into the rows. Thus, it was considered that a combination of this behavior of the beetles and an insecticide, such as chlorpyrifos-methyl and fenitrothion, will provide a longer residual efficacy on the insect adults.

In this work, residual contact efficacy on the cigarette beetle adults on various material surfaces treated with chlorpyrophos-methyl was evaluated. Furthermore, in order to provide long-term control of the cigarette beetle adults, the residual efficacies of the corrugated papers treated with the four insecticides were evaluated in the laboratory.

MATERIALS AND METHODS

Insects and insecticides. The cigarette beetles were obtained from a population that had been maintained in the Leaf Tobacco Research Center of
Japan Tobacco Inc. They were reared in 900 ml plastic jars (13 cm in diameter, 5.5 cm in depth) containing ca. 200 g diet under constant laboratory conditions of 27°C, 60% RH, and a photoperiod of 16 : 8 (L : D) h. The diet was a mixture of corn flour and dried yeast powder (10 : 1 w/w). Insect adults within 2 d after the first emergence on the surface of the diet were used for the bioassay.

Insecticides used in this work were the following commercial formulations: chlorpyrifos-methyl 25% emulsifiable concentrate (EC), Reldan® 25 (Nissan Chemical Industries, Ltd.); pirimiphos-methyl 45% EC, Actellic® (Nihon Nohyaku Co., Ltd.); fenitrothion 50% EC, Sumithion® (Sankyo Co., Ltd.); and permethrin 20% EC, Adion® (Sankei Chemical Co., Ltd.).

Residual efficacy on the different material surfaces treated with chlorpyrifos-methyl. Six different kinds of material panels (corrugation of corrugated paper, Japan cedar, overlaid plywood for flooring, painted iron plate, aluminum foil, and concrete) were cut or divided into square pieces (10 cm×10 cm). Each panel (10 cm²) was treated by pipetting 1.0 ml dilute acetone solution to achieve a uniform distribution of the insecticide at a rate of 250 mg AI/m² of chlorpyrifos-methyl, and was then allowed to dry for 3 h at room temperature. Residual efficacy of the insecticide was determined by exposing insect adults to the treated panel surface. The inside of a glass ring (7.0 cm in diameter, 3.5 cm in depth) was coated with Kure-polymate® natural (Kure Engineering Ltd.) to prevent the insect adults from climbing the inside surface, and then this glass ring was put on each treated panel surface. Twenty insect adults were released into the glass ring, and exposed on the treated panel surface for each confined contact time (1, 5, 10, 30, and 60 min). Then, the insect adults were transferred into a clean plastic cup (6 cm in diameter, 3.5 cm in depth) with a ventilated cover, and these cups were kept for 2 d in an incubator at 25°C for an assessment of mortality. The treated panels were stored under constant laboratory conditions of 27°C, 60% RH, and a photoperiod of 16 : 8 (L : D) h. Residual efficacy was examined using the same panel immediately after treatment, and 2 and 4 weeks after storage. Each experiment was replicated four times. An adult was considered to be dead if it failed to walk normally after the plastic cup containing the insect adults was shaken. Percentage mortality was calculated from the total mortality recorded in the four replicates and corrected using Abbott’s formula (Abbott, 1925).

Bioassay using corrugated paper. The corrugated paper used in this work was 5 mm in the vertical caliber of a pipe and 34±2 in the number of pipe rows per 30 cm in length. The corrugated paper was cut across the pipe rows into strips of 0.5 cm, 1.0 cm, and 2.0 cm in width. Two centimeter wide strips were used for the bioassay of repellency and residual efficacy; the strips of paper were treated by pipetting 0.6 ml dilute acetone solution per 8 cm in length at a rate of 125, 250, 500, or 1,000 mg AI/m² of each of the four insecticides onto them. The strips were left to dry overnight at room temperature, and then double-sided tape (Nicetack® NW-20, Nichiban Co., Ltd.) was put on one side of each strip. Four 23 cm lengths of each width of corrugated paper (0.5 cm, 1.0 cm, or 2.0 cm) were cut, and arranged in a square on the floor of a transparent insect cage (35 cm×35 cm, 50 cm in height) made of vinyl chloride, the four...
sides which were made of a fine net (Fig. 1). Then, 100 or 200 cigarette beetle adults were released from the center of each floor. All bioassays were conducted under constant laboratory conditions of 27°C and a photoperiod of 16:8 (L:D) h.

**Settling behavior on corrugated paper.** Behavior of the cigarette beetle adult was observed using the corrugated paper of 0.5 cm, 1.0 cm, and 2.0 cm in width. The number of insect adults escaping from the corrugated paper was counted 1, 3, 5, 24, 48, and 72 h after release. Settling rate of the 200 released cigarette beetle adults was calculated, and compared among the different widths. Each experiment was replicated three times.

**Repellency on corrugated paper treated with insecticides.** The settling rate of the cigarette beetle adults was evaluated on corrugated paper treated with the four insecticides. The insect adults escaping from the corrugated paper were sucked up with a vacuum to count their number 10 min and 20 min after release. The settling rate of the 100 released cigarette beetle adults was calculated, and the data for the different insecticides was compared. Each experiment was replicated six times.

**Residual efficacy on corrugated paper treated with insecticides.** Residual efficacy on the corrugated paper treated with the four insecticides was evaluated using the same corrugated paper immediately after treatment and 4 months after storage under conditions of 27°C, 60% RH, and a photoperiod of 16:8 (L:D) h. The 200 insect adults were released, and the mortality was assessed 4 d after release, as described above. Each experiment was replicated three times.

### RESULTS AND DISCUSSION

**Residual efficacy on the different material surfaces treated with chlorpyrifos-methyl**

Residual efficacy of chlorpyrifos-methyl on the different material surfaces is shown in Table 1. The contact time of 1 min achieved 100% mortality immediately after treatment on all the material surfaces.

A loss of active ingredients results from evaporation, photodegradation, chemical degradation, removal by cleaning or abrasion, uptake by the insects and absorption into the surface (Chadwick, 1985). The residual efficacy on such material surfaces as painted iron plate, aluminum foil, overlaid plywood and concrete decreased sharply with time, and toxicity was completely lost at a contact time

<table>
<thead>
<tr>
<th>Storage period after treatment</th>
<th>Material treated with insecticide</th>
<th>1</th>
<th>5</th>
<th>10</th>
<th>30</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediately after treatment</td>
<td>Paper</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wood</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Iron plate</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aluminum foil</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plywood</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 weeks after storage</td>
<td>Paper</td>
<td>0</td>
<td>3.8</td>
<td>70.5</td>
<td>87.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wood</td>
<td>1.3</td>
<td>0</td>
<td>12.5</td>
<td>27.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Iron plate</td>
<td>1.3</td>
<td>1.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aluminum foil</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plywood</td>
<td>0</td>
<td>1.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 weeks after storage</td>
<td>Paper</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wood</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

*paper: corrugation of corrugated paper; wood: Japan cedar; iron plate: painted iron plate; plywood: overlaid plywood for flooring.*
of 60 min 2 weeks after storage. A large portion of chlorpyrifos-methyl on overlaid plywood, aluminum foil and painted iron plate can be lost by vaporization, chemical degradation, or photodegradation because of lower absorption on these surfaces. Much of the chlorpyrifos-methyl on concrete will be absorbed into the porous surface; furthermore, the active ingredient may be chemically degraded in concrete.

In contrast, residual efficacy on material surfaces of the corrugation of corrugated paper and Japan cedar showed 87.3% and 27.2% mortalities, respectively, at a contact time of 60 min 2 weeks after storage, but toxicity was completely lost at a contact time of 60 min 4 weeks after storage. The corrugation of corrugated paper showed the longest residual efficacy. This fact indicates that corrugated paper is one of the most suitable materials for preserving long-term residual efficacy of insecticides.

The corrugation of corrugated paper, or Japan cedar absorbed chlorpyrifos-methyl may retain the active ingredient in its thick layer, and this may protect the active ingredient from evaporation, photodegradation, and chemical degradation.

### Settling behavior on corrugated paper

The settling rate of the cigarette beetle adults on corrugated paper of different widths is shown in Table 2. The settling rates 1 h and 5 h after release on the corrugated paper of 2.0 cm in width were significantly higher than those of the 0.5 cm width, and the rate at the other observed times was the same level as that of 0.5 cm and 1.0 cm width. Most of the released cigarette beetle adults readily settled in the corrugated paper, and the range of settling rates throughout the observation time was 88.7–97.0%.

*Anthrenus verbasci* L. adults showed negative phototaxis when they emerged from the last larval exuviae, and they laid most of their eggs before becoming positively phototactic (Kuwana, 1950; Kiritani, 1958). The cigarette beetle adults used in this work were those within 2 d after first emergence on the surface of diet which is probably the reason that these adults showed negative phototaxis, the response away from light of most of them settling in the corrugated paper. It is important in controlling the insect adults to research the response of adult females against the corrugated paper after oviposition.

### Repellency on corrugated paper treated with insecticides

The settling rates on the corrugated papers treated with the four insecticides are shown in Table 3. The corrugated papers treated with chlorpyrifos-methyl, pirimiphos-methyl, and fenitrothion at all dosages showed as high settling rates (>97.3%) as the controls, regardless of the time after release. In other words, these three insecticides showed no repellency to the insect adults. The corrugated paper treated with permethrin showed significantly lower settling rates than the control, exhibiting especially significantly different settling rates among all dosages 20 min after release.

### Residual efficacy on corrugated paper treated with insecticides

Residual efficacies of these strips treated with the four insecticides are shown in Table 4. The corrugated papers treated with chlorpyrifos-methyl, pirimiphos-methyl, and fenitrothion consistently achieved almost 100% mortality immediately after treatment, regardless of the dosages of the insecticides. Residual efficacies of these strips decreased

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**Table 2. Settling rate of *Lasioderma serricorne* adults on corrugated papers of three width sizes**

<table>
<thead>
<tr>
<th>Width (cm)</th>
<th>Settling rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>0.5</td>
<td>88.7 a</td>
</tr>
<tr>
<td>1.0</td>
<td>92.3 b</td>
</tr>
<tr>
<td>2.0</td>
<td>94.0 b</td>
</tr>
</tbody>
</table>

*Frequency data were subjected to the arcsine square root-transformation before analysis. Values with the same letter in the same column are not significantly different at the 5% level by Tukey’s test.*
4 months after storage, but the strips maintained high mortality with increase of the treated dosages to the corrugated paper. The AI dosages which achieved more than 90% mortality 4 months after storage were in 250, 500, and 1,000 mg AI/m² of chlorpyrifos-methyl, 500 and 1,000 mg AI/m² of pirimiphos-methyl, and 1,000 mg AI/m² of fenitrothion. Chlorpyrifos-methyl and pirimiphos-methyl, as insecticides for treating corrugated paper, provide a better and significantly longer residual efficacy than fenitrothion. Mortalities of all dosages of permethrin applied to the corrugated paper were significantly lower than the mortalities of the other three insecticides at a dosage of 125 mg AI/m² immediately after treatment, and differed significantly among all the dosages of permethrin.

The behavior of the cigarette beetle adults settling in the corrugated paper for a prolonged time will guarantee contact time long enough to kill the insect adults. This is why the corrugated paper treated with the insecticides provides an excellent residual efficacy on the insect adults.

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The behavior of the cigarette beetle adults settling in the corrugated paper for a prolonged time will guarantee contact time long enough to kill the insect adults. This is why the corrugated paper treated with the insecticide provides long-term residual efficacy on the cigarette beetle adults.

Of the 16 insecticides evaluated by the dipping method, the ones most toxic to the cigarette beetle adults were chlorpyrifos-methyl, pirimiphos-methyl and fenitrothion, while the toxicity of permethrin was relatively lower than that of most other insecticides (Orui, 1993). These results suggest that the corrugated paper treated with the insecticides with a very high insecticidal activity and no repellency to the cigarette beetle adults provides an excellent residual efficacy on the insect adults.

The corrugated papers of 2 cm in width treated with chlorpyrifos-methyl (250 mg AI/m²) were set using double-sided tape on the vinyl floor tile facing all over the wall in the room (2.7 m×5.4 m, 2.5 m in height) under conditions of ca. 27°C and a photoperiod of 16:8 (L:D) h. When 4,000 cigarette beetle adults were released from the center of
this room after 1 month, residual efficacy of this corrugated paper on the insects adults showed more than 80% mortality (Orui, unpublished).

As the corrugated paper treated with an insecticide does not have enough strength to attract the cigarette beetle adults, whether the adults get into it depends upon their random movement. Therefore, this corrugated paper should be set using double-sided tape on surfaces, where the insect adults will definitely walk on the basis of our knowledge of the adult insect’s behavior. A narrow strip of corrugated paper treated with a small amount of insecticide has a prolonged residual efficacy, and so could help reduce both the cost of frequent insecticide treatments and the risks of insecticide contamination.

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REFERENCES

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