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IMPROVING THE EFFICIENCY OF STICKY MONITORS FOR BED BUGS, *CIMEX LECTULARIUS*

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Abstract Bed bug (*Cimex lectularius*) monitors are effective tools in detecting early infestations and evaluating the results of control programs. Among the monitors, bed bug sticky monitors are not toxic and easy to use. But we observed that that bed bugs were repelled by the contact between the sticky film on the floor and their legs. Second problem, when they were caught by only the tip of one leg, bed bugs might sometimes get off the sticky monitor. Our studies showed that, instead of coating the floor with glue, coating the interior surface of a sloping roof increased the efficiency of the monitor. The legs were not directly in contact with the sticky substance which was not detected by bed bugs. They entered into the monitor without repulsive behavior. Bed bugs could not escape as they were glued by their back. After one night, the number of caught bed bugs in a monitor with the sticky film under the roof was multiplicated by 7 when compared to a monitor with a sticky floor. We developed monitors with the sticky film coating the interior surface of the roof. We studied the optimal slope of the roof and the optimal height of the entrance. Monitors with sticky roof were also efficient with other species: 88% of woodlice (*Oniscus asellus*), 100% of ants (*Myrmica* spp.) and 100% of cockroaches (*Blatta lateralis*) were glued by their back after one night.

Key words Monitors glue roach woodlice ant

INTRODUCTION

Bed bugs are very difficult to find and the elimination can be quite costly to control if not detected early. Additionally, it is difficult to determine if any bed bugs are still present following control treatment (Wang et al., 2016). Many commercial bed bug monitors are available for detecting bed bugs and among them, monitors with sticky floor have the advantage to be easy to use without the addition of any toxin. With these monitors, many other bugs can be trapped, which allow to identify what type of pest is biting. Research (Wang et al., 2009, 2011, 2016) has shed light on the impact monitoring devices have on low level bed bug infestations (less than 10 bed bugs). This research demonstrated that 50% of low level bed bug infestations can be eliminated solely through the installation of monitors around the bed and along the baseboards throughout homes. We do not suggest using only interception devices to solve bed bug infestations, but we think that such monitors can help reduce the amount of pesticides needed to control bed bugs as well as demonstrate how important early detection is in reducing cost and effort to solve problems. Monitors should be effective tools in detecting early bed bug infestations and evaluating the results of bed bug control programs. The first problem with monitors with sticky floor is that bed bugs are repelled by the contact between their legs, or their ventral side, and the sticky film applied on the floor. Many monitors for insects comprise a sticky film applied on the top surface of a substrate. Insects are repelled by the contact between their legs, or their ventral side, and the sticky film applied on the floor. Therefore, insects escape from the monitor upon first contact and are not trapped. The second problem is that insect glued by the tip of their legs escape, sometimes by abandoning a leg. Our studies was focused on how to resolve these two problems to improve these type of monitors, taking the behavior of bedbugs in account (Benoit, 2011). In this paper, we show the different steps of the development of an efficient monitor where there is no repulsive behavior due to the contact with the glue and where glued insects cannot escape. We also compared it to some of some monitors on the market.

MATERIEL AND METHODS

Rearing. Bedbugs were reared in plastic bottles containing a filter paper folded in accordion fashion to provide a refuge and a support for egg laying. They were placed in an incubator at a temperature of 21°C and were fed once a week with human fresh blood not containing anticoagulant. Experiments were performed in a suitable room at a temperature of 20°C with a relative humidity of 30-50%.

Efficiency. To test the efficiency of the monitors, we placed them in a plastic tray of 30 x 20 cm, of which the bottom was sanded with sandpaper. Fifteen bedbug individuals (5 males, 5 females and 5 nymphs of all stages) were placed in the tray. The number of individuals glued to the double-sided adhesive tape was noted after 15 hours. This procedure was repeated 3 times. It was used in order to measure the efficiency of a monitor . We also used it to compare the efficiency of 2 monitors.

Monitor with a sticky roof. Coating the interior surface of the roof of a monitor might be a way to avoid the repulsive behavior as insects do not touch the glue with their legs. This experiment aimed to determine whether such a monitor was effective or not. The monitor used in this experiment was designed like a shelter (Figure 1ab). All stages were very thigmotactic with the solid walls of these crevices (Benoit, 2011). Our objective was to make a monitor which looks like a crevice where every stages (nymphs or adults, whatever their length) were in contact with the wall of the shelter. The monitor was a long thin rectangular monitor with a triangular section. The sloping roof was sticky with double-sided adhesive tape (AXTON®) on its interior surface. The efficiency of this monitor with a sticky roof was tested following the procedure described above.

Optimal dimensions. To obtain an optimal architecture for a monitor with a sticky roof, we tested 4 different heights of the opening: 1.5 mm, 2.5 mm, 5 mm and 10 mm and 4 different depths (that determine the slope of the monitor) : 5 mm, 15 mm, 25 mm and 35 mm. The efficiency of these monitor with sticky roofs was tested and compared following the procedure described above.

Sticky roof vs. sticky floor. A monitor with double-sided adhesive tape sticky on the interior surface of the roof and a monitor with double-sided adhesive tape sticky on the upper surface of the floor were placed in the plastic tray. The efficiency of these two types of monitors was tested following the procedure described above (N=3).

Alarm pheromone. Two monitors were placed face to face in a plastic tray of 30 x 20 cm, one linear monitor with bed bugs already stuck inside (1, 5, 10 or 20 individuals) and one monitor with no bed bugs inside. 30 bedbugs (10 males, 10 females and 10 nymphs of all stages) were placed in the tray. The number of individuals inside each monitor was noted after one night. 3 replicates were run for each number of bed bugs already stuck inside the monitor.

Catch other insects. Monitors with a sticky roof were placed in a plastic tray of 30 x 20 cm, of which the bottom was sanded with sandpaper without any attractive agent. Three crawling insect species were tested: woodlice (*Oniscus asellus*), ants (*Myrmica* spp.) and cockroaches (*Blatta lateralis*). Opening heights and monitor length were tested according to the crawling insects size. The number of trapped individuals was observed after one night.

Sticky roofs vs. commercial monitors. Three different commercially available monitors were placed one by one in a plastic tray of 120 x 95 cm vis-a-vis the monitors with sticky roof. The 3 commercially available monitors used for this test comprised a sticky substance on the floor. We tested only the efficiency of architecture by using the glue of the commercial monitor to coat the roof of the control monitor (same glue, different position of the glue).

RESULTS

Monitor with a sticky roof. After 15 hours, 73% of the males, 80% of the females, and 68% of the nymphs were glued to the roof of the monitor.

Optimal dimensions. Whether individuals are males, females or nymphs, a monitor with a depth of 15 mm lead to significantly more trapped individuals than a length of 25 or 35 mm (figure 2a; chi-square, $P<0,05$). The optimal opening height was set at 1.5 mm (Figure 2b; chi-square, $P<0,05$). The maximal efficiency of the monitor was reached with a roof slope ranging from 0.1° to 0.3°. The monitor had 9 walls, 2 external walls and 7 internal walls, delimiting 9 interstices of 15 mm in length; These walls were there to support the roof and prevent that the sticky roof from collapsing and gluing to the floor.

Sticky roof vs. sticky floor. Individuals (males, females or nymphs) significantly sheltered into monitor with sticky roofs, compared to sticky floor monitors. Either sex and stages, 88% of individuals were trapped into monitor with sticky roofs (N repetitions=3; Chi-square test).

Table 1. Comparison between the efficiency of monitor with a sticky roof versus monitors with a sticky floor.

	Sticky floor	Sticky roof	p-value
Total	9	64	<0.001
Males	0	28	<0.001
Females	6	19	0.016
Nymphs	3	17	0.0037

Alarm pheromone. Results showed that bed bugs sheltered in both the monitor with glued individuals and in the monitor without any glued individuals. Therefore, glued bed bugs did not emitted alarm pheromone. Moreover, we observed that the more bedbugs were glued to the adhesive tape, the more other bed bugs sheltered in this monitor compared to the monitor without glued individuals. When 1, 5, 10, 20 bed bugs were stuck in the glue, the % of glued bed bugs was 50%, 46%, 72% and 87.5% after one night. Therefore, glued bedbugs were attractive for free bed bugs. The monitor efficiency thus gradually increased as bed bugs are captured.

Catch other insects. Up to 94% and 100% of woodlice, ants and cockroaches were glued in the monitor after one night. For a maximal efficiency, the depth of the monitor and the height of the opening should be adapted to the size of crawling insects. The dimensions should be greater for cockroaches than for ants. The results presented in Table 2 show the relationship between the minimal opening height and the crawling insects' size was linear (Figure 3). The height of the monitor openings can be estimated by plotting the crawling insects' height on the line and by reading the value on the vertical (y) axis.

Table 2. Efficiency of a monitor with a sticky roof with different crawling insects species

Species	Opening height (mm)	Monitor depth (mm)	% of glued animals (%)
Woodlouse	1.5	15	50
	2.5	15	94
Ant	1.5	15	100
Cockroach	2.5	70	0
	5	70	100
	10	70	80
	15	70	100

Sticky roofs vs. commercial monitors. Buggybeds® (HitchhickersTM), Bedbug alert monitor (Bird-X Inc) and Bedbug detection systemTM (Catchmaster®) trapped respectively 1%; 1% and 17 % of bed bugs (N repetition =3). The monitor with sticky roof caught 74% of bed bugs (N repetition =3). Therefore, the monitor with a roof sticky was significantly more efficient than commercially available monitors (chi-square, P<0,005 for all comparisons).

CONCLUSIONS

To suppress bed bug infestations and reduce further bed bug dispersal, the first step is to adopt a proactive building-wide bed bug monitoring policy (Copper, 2015; Wang 2016). Therefore efficient monitors are needed. By coating the

glue on the interior surface of the roof, the insects do not get in touch with the glue by their legs and do not detect it. They are glued by their back with is more efficient than by the tip of the legs (larger surface). Glued insects do not emit alarm pheromone that alert other individuals. Quite the contrary, the monitor efficiency gradually increases as crawling insects are captured. Therefore, the glued insects produce signals that attract other individuals. It is possible that there is an active emission of attractive pheromone. It is more probable that some cuticular hydrocarbons (protecting the insects from desiccation) might be passively deposited in the glue and act as attractants for the free bugs. This snowball effect is interesting as the efficiency of the monitors increases with time, the glued insects being the attractant for the others. Our results show that, with the glue coating the interior surface of the roof, these monitors are more effective than monitors with sticky floor. The result is confirmed by a study on the field made by Snell showing that, with 3 monitors with a sticky roof in a bed, the presence of bed bugs in a bedroom was detected with a 100% detection rate (3 iterations) while in the same conditions, the Catchmaster monitor did not detect any of the bugs. Monitors with a sticky roof are also easy and safe to be handled and used, they do not require the use of fluid or powder like talcum powder as in the case of pitfall capture. This has the advantage of providing a clean and easy way to detect bedbugs. Another advantage of this type of monitor is that it is designed for a wide variety of crawling insects species, preferably insects and/or arachnids, and sizes due to sufficiently large openings. Crawling insects may enter through sufficiently large openings and then go deeper into the monitor until they reach the height of the roof that corresponds to their size. At this point, they touch the sticky roof and are captured. Last advantage of this type of monitor, its design is discreet, adapted to be placed along walls or under bed foot for example. This advantage may be useful under particular conditions such as in hotel rooms.

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