Attract-and-Kill and Other Pheromone-Based Methods to Suppress Populations of the Indianmeal Moth (Lepidoptera: Pyralidae)

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ABSTRACT Three attract-and-kill formulations, a gel, a wax panel, and a plastic cylinder were tested in simulated warehouses at three densities of devices and at three densities of moths, *Plodia interpunctella* Hübner, per room. Wax panels and the cylinder formulations suppressed all the densities of moths with only one device per room. Two field experiments were then conducted during 2005 and 2006 in replicated commercial pet food and grocery stores that harbored natural populations of *P. interpunctella*. In the summer of 2005, the wax panel formulation suppressed adult male response to monitoring traps and also reduced the numbers of larvae in food bait oviposition cups after the first month of being established. This suppression was maintained until the third month. The second field experiment in 2006 compared three pheromone-based methods of moth suppression in buildings with moth populations in untreated buildings. The mass-trapping treatment showed the lowest adult moth capture after the first month of the experiment until the end of the third month. However, this treatment was similar statistically to use of attract-and-kill panels, mating disruption, and untreated control establishments in most of the weeks. Monitoring of larvae in food cups revealed the pheromone-based methods were not significantly different from each other, but that they suppressed moth populations in most of the weeks when compared with untreated control buildings. This research shows potential for successful pheromone-based suppression methods for Indianmeal moths in commercial applications.

KEY WORDS stored product, attracticide, male annihilation, mating disruption, pyrethroid

The major female sex pheromone of *Plodia interpunctella* (Hubner) was identified in 1971 as (*Z,E*)-9,12 tetradecadienyl acetate "ZETA" (Brady et al. 1971, Kuwahara et al. 1971), with elaboration of additional sex pheromones in following years (Kuwahara and Casida 1973, Sower et al. 1974, Soderstrom et al. 1980, Teal et al. 1995, Zhu et al. 1999), and the use of ZETA in pest management of this important pest has been implemented in different ways. The main uses of pheromones for stored-product pests are as attractant lures in traps for detection and monitoring storage pests (Phillips 1997), in food storage areas, processing factories (Hoppe and Levinson 1979; Vick et al. 1981, 1986), wheat storage bins (Hagstrum 2000), in and around flour Mills (Doud and Phillips 2000) and pilot feed mills (Roesli et al. 2003). Pheromone lures for *P. interpunctella* are often deployed in sticky traps that offer advantages over visual inspections (Mullen and Dowdy 2001), and are valuable tools for determining spatial and temporal distribution and encourage the use of integrated pest management programs (Mueller 1998) and in enclosed environments are useful for making management decisions against insect pests (Burkholder and Ma 1985). In addition, the longevity of lures enhances trap-catch efficiency (Mullen et al. 1991). For example, the efficiency and longevity of *P. interpunctella* sex pheromone was tested in a warehouse where the attractiveness of Storgard lures (Trécé Inc., Salinas, CA) and Biolure lures (Consep Membranes Inc., Bend, OR) were up to 40 wk, a time period beyond manufacturers' claims (Mullen et al. 1991). More recently, and in the context of this report, ZETA has been used in mating disruption to suppress pest populations of stored-product moths (Phillips and Throne 2010) rather than simply to monitor them.

The use of the pheromones for suppressing insect pests has been studied widely in Lepidoptera with the goal being to reduce the population by killing mainly males or in other ways to prevent mating to females. Mass-trapping is a method based on the catching and killing of as many males as possible and thus to reduce the proportion of mated females, and ultimately the pest population level, in storage habitats (Chow et al. 1977, Levinson and Buchelos 1981, Muller and Pierce 1992, Trematerra 1994). Mating disruption is used by releasing high levels of synthetic pheromone so that the male moth is not capable of finding the female, either from "false trail-following" of males to synthetic pheromone dispensers, or some neural disruption in

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male behavior (Cardé and Minks 1995). The disruption in mating can result in a reduction of up to 93% in the density of a *P. interpunctella* population in small-scale plots (Ryne et al. 2001). Mating disruption of storage mots was demonstrated in Europe in the field in short-term (Ryne et al. 2006) and long-term studies (Ryne et al. 2007, Sieminska et al. 2009). In North America mating disruption was demonstrated for *P. interpunctella* in wheat seed, animal feed, and green coffee (Phillips 2006) and for *Sitrotoga cerealella* (Olivier) (Vick et al. 1978) and *Ephestia cautella* (Walker) (Mafra-Neto and Baker 1996, Shani and Clearwater 2001, Fadamiro and Baker 2002) infesting stored corn. At present, there are at least two registered commercial products for mating disruption of stored-product moths in the United States (reviewed in Phillips and Throne 2010). These registrations were facilitated by the U.S. EPA exempting ZETA from a requirement of a food residue tolerance when used indoors to protect stored food commodities (Environmental Protection Agency [EPA] 2006).

Another type of pheromone-based suppression is the "attract-and-kill" method that is a combination of a sex pheromone and a killing agent, such as a pathogen or insecticide (Lanier 1990), and is also known as "lure and kill," "attraction–annihilation," or "attracticide." Attract-and-kill may target males, females or both, depending on the system, and this technique has been studied in important Lepidoptera pests in stored-products like navel orangeworm *Amyelois transitella* (Walker) (Phelan and Baker 1987) and the Mediterranean flour moth *Ephestia kuehniella* Zeller (Trematerra and Capizzi 1991). Recent work on *P. interpunctella* investigated the contact toxicity of pyrethroids and pyrethrins, including organic pyrethrins, that suppressed up to 70% of adult males (Campos and Phillips 2010). Furthermore, wind tunnel bioassays showed that attract-and-kill formulations with pyrethroids and pyrethrins last up to 4 wk (Campos and Phillips 2013). Earlier work showed that the attract-and-kill formulation LastCall gel was able to suppress oviposition only at the lowest populations density (1 male:1 female) in simulated small warehouses of 11.3 m^3 (Nansen and Phillips 2004).

The overall objective of the work reported here was to determine the efficacy of attract-and-kill devices for suppressing pest populations of Indianmeal moth, and to compare the use of attract-and-kill devices with mass-trapping and mating disruption. Three experiments were conducted, each with specific objectives. First was to determine the effectiveness of three different attract-and-kill formulations for suppressing small artificial populations of *P. interpunctella* under controlled conditions in simulated warehouses. A second experiment was designed to assess the "wax panel" attract-and-kill formulation in actual commercial establishments with naturally occurring Indianmeal moth populations. The third experiment compared the pheromone-based control methods of attract-and-kill, mating disruption, and mass trapping in several commercial establishments.

Methods and Materials

Insects. *P. interpunctella* male and female adults used in simulated warehouses were reared on diet containing corn meal, chick starter and grower crumbles, all mash egg crumbles, and glycerol (4:2:2:1 by volumetric ratio) in 460-ml glass jars (Alltrista, Muncie, IN) placed in a growth chamber at 28°C, 60–70% relative humidity (RH), and a photoperiod of 16:8 (L:D) h (Phillips and Strand 1994). Cardboard rolls were placed into the culture jars for the last stage wandering larvae to crawl into and pupate. The pupae were removed from the cardboard rolls, separated by sex, and placed individually into 1-dram shell vials with ventilated plastic caps (Fisher, Pittsburg, PA) and returned to the growth chamber until they emerged as adults. One- to 2-d-old virgin adults were used for the simulated warehouse studies, and these adults were only used once.

Simulated Warehouse Experiments. The experiments were conducted using four separate commercial "mini-storage" rooms located near Stillwater, OK. The building was divided into several main sections by halls and doors; and every section contained six to seven individual storage rooms. The dimensions of the storage rooms used were 3.3 by 3.3 by 6.6 m, for a volume of 71.9 m^3. The storage rooms were composed of a concrete floor, sheet-metal walls, and a sheet-metal roof that was installed in the ceiling; the entrance was a metal roll-up over-head door. The storage rooms were equipped with minimal climate control so that the air temperature was kept between 25 and 30°C in the summer season. The upper side of the side walls had a 10-cm-wide gap that was covered with a plastic sheet to prevent insects from escaping or entering the storage rooms. A plastic sheet was hung just inside the door to each room and was sealed with tape and Velcro to the ceiling walls and floor to prevent adult *P. interpunctella* from flying away when the experimental room was being serviced.

Three attract-and-kill formulations, described also by Campos and Phillips (2013), were tested in a series of experiments. The first formulation was the LastCall gel applied as a 100 mg droplet onto a 4 by 4 cm piece of aluminum foil. The gel contained the pheromone ZETA at 0.16% by weight and the pyrethroid insecticide Permethrin at 6%. The second formulation was the wax panel (20 by 13 cm; Suterra, Bend, OR) impregnated with Permethrin at 6% and deployed with a Biolure controlled release pheromone lure (Suterra). The third formulation was a plastic mesh cylinder (7 mm mesh; 35 cm in length by 10 cm in diameter) coated with the pyrethroid cyfluthrin at 2% in the spray and deployed also with a Biolure lure. In treated mini-storage rooms the attract-and-kill devices were held with a small binder clip and hung from the ceiling with a steel wire at ≈1.55 m from the floor. Experimental treatments, which were different numbers of a given attract-and-kill device, were randomly assigned to the four mini-storage rooms and deployed on Mondays and finished on Fridays for each replicate. One 15- by 90-mm petri dish bottom containing 15 g

of wheat as an egg-laying substrate was distributed close to each of the four corners of each room and placed on wood boards (5 by 7.5 by 7.5 cm) to avoid direct contact with the floor. Two-day-old male and female adults of *P. interpunctella* were released at opposite ends of the room, close to the walls. Petri dishes were retrieved from each room at the end of the 4-d exposure period, labeled, and transported to the laboratory for processing. The wheat from each petri dish was sifted with a standard U.S. No. 14 seive and the number of eggs laid in each dish was counted.

Experimental Design and Data Analysis for Simulated Warehouses. The three attract-and-kill formulations (gel, wax panel, and the cylinder) were tested in nine separate 4-wk-long simulated warehouse experiments at treatments of 0 (untreated control), 1, 2, or 3 attract-and-kill devices per mini-storage room; separate experiments for each formulation were conducted at moth densities of 5, 10, and 15 male–female pairs released per room. The response variable observed after each replicate was the number of eggs laid per dish of wheat in each room during the 4-d study period. It was a three factorial design (number of moths per room, number of devices per room, and three types of formulations) with four replicates (one replicate per week) and analyzed with PROC MIXED in SAS/STAT 9.00 for Windows (SAS Institute 2005). Mean separations were made with Least Significant Difference test.

Field Experiments. Two studies of pheromone-based suppression of *P. interpunctella* populations were conducted during the spring and summer months of 2005 and 2006 in the metropolitan area of Dallas, TX. The 2005 study assessed the attract-and-kill wax panels compared with untreated buildings and included five pet food stores and three small grocery stores for a total of eight buildings; four buildings were designated untreated controls and the remaining four buildings received attract-and-kill wax panels. The second field experiment in 2006 used six pet food stores, eight grocery stores and one small pet food warehouse for a total of 15 buildings, and it compared attract-and-kill, mass trapping, mating disruption (n = 4 buildings each), and untreated control buildings (three buildings). For each commercial establishment, the types of food products were identified and building space measurements were taken to calculate the volume of each building. Because the wax panel was effective at its lowest deployment density in the simulated warehouse studies, which was one panel per 71.9 m^3, the treatments were applied to the commercial buildings at that same density.

In 2005, only the attract-and-kill wax panel (Suterra) formulated with 6% Permethrin and a Biolure pheromone lure (Suterra) was used and compared with untreated buildings. In 2006, an attract-and-kill panel was made with a 20- by 13-cm piece of plastic-coated paper (same material used in diamond sticky traps, but without glue material; Suterra), and sprayed to run-off with the pyrethroid formulation Deltamethrin at 0.08% (a.i.) and deployed with a Biolure lure. A standard diamond-shaped sticky trap (Suterra) was used for the mass-trapping treatment, which was also deployed with Biolure lures at the same density as attract-and-kill panels, and the mating disruption treatment used only Biolure lures at the same density as other treatments. Buildings used for field studies in 2005 and 2006 were selected because they were similar in size, accessibility for monitoring moths and deploying treatments, and were known to have similar levels of *P. interpunctella* activity based on preliminary trapping observations. Experimental treatments were assigned to buildings at random in each year. The pheromone-based mitigation methods were compared with each other (2006) and to similar buildings that were untreated controls (2005 and 2006) during the same time periods in a given year with treatment effects analyzed only within a defined time period on a bi-weekly basis (see below).

Moth Population Variables. Adult males were monitored in both the 2005 and 2006 field trials using diamond-shaped sticky traps (Suterra) deployed with a Biolure lure. Ten sticky traps were used per store, and these were left over a weekend, from Friday to Monday, every 2 wk over about a 12-wk period. We started the pheromone trap monitoring in every building 2 wk before the treatments were assigned to the buildings. Once the treatments were set up, they were left for 3 mo in each year. The moth population in each building was also monitored by counting larvae developing in 10 Styrofoam baits cups (226 ml; Dart, United States) per store. Each bait cup contained 50 g of laboratory rearing diet (see above) and were distributed evenly throughout each building and replaced every 2 wk, usually on a Monday at the end of a 3-d pheromone-trapping period, during the 3 mo of the experiment. The bait cups were returned to the laboratory and placed in a growth chamber at 28°C, 60–70% RH, and a photoperiod of 16:8 (L:D) h for another 2 wk, after which they were put in a heated sand bath (55 ± 5°C) until the larvae crawled up and out of the diet, escaping from heat, and they were counted.

Experimental Design and Data Analysis for Field Trials. For the 2005 experiment, the wax panel was compared with untreated controls; it was a balanced completely randomized design with four buildings assigned the treatment and four untreated, and observed over a 3-mo period. In 2006, the attract-and-kill panel, mass trapping, and mating disruption methods were compared with the untreated control building. Each pheromone-based treatment was assigned to each of four stores, and only three stores were designated untreated controls, so this was an unbalanced completely randomized design. The number of males per sticky trap and the number of larvae per bait cup were analyzed by PROC MIXED in SAS/STAT 9.00 for Windows (SAS Institute 2005) with repeated measures option (every 2 wk during the 3-mo period) followed by a means separation (LSMEANS) to test for differences in captures and larvae by date and treatment.

Table 1. Mean number of eggs laid (±SE) per petri dish for the three attract-and-kill formulations (gel, wax panel, and cylinder) at densities of 0, 1, 2, and 3 devices per warehouse room and at three densities of moths (5, 10, and 15 pairs)

Formulation	Pairs of moths	Density of devices per warehouse room (56.64 m^3) (±SE)			
		0	1	2	3
Gel	5	15.9 ± 4.8B,a	7.3 ± 7.2A,a	5.4 ± 4.0AB,a	0.6 ± 0.6A,a
	10	32.3 ± 6.6AB,a	16.3 ± 9.6A,a	16.3 ± 9.7AB,a	13.0 ± 4.8A,a
	15	37.6 ± 4.6A,a	17.7 ± 1.9A,ab	18.1 ± 5.9A,ab	15.7 ± 9.5A,b
Wax panel	5	20.9 ± 8.2AB,a	1.0 ± 0.8A,b	0.0 ± 0.0B,b	0.0 ± 0.0A,b
	10	17.5 ± 8.2AB,a	2.4 ± 1.5A,b	0.2 ± 0.1B,b	0.0 ± 0.0A,b
	15	25.2 ± 7.5AB,a	2.0 ± 1.0A,b	0.1 ± 0.1B,b	0.0 ± 0.0A,b
Plastic cylinder	5	15.8 ± 6.0B,a	3.1 ± 2.4A,b	0.0 ± 0.0B,b	0.0 ± 0.0A,b
	10	32.9 ± 6.8AB,a	6.3 ± 2.5A,b	0.6 ± 0.5B,b	0.0 ± 0.0A,b
	15	25.8 ± 7.7AB,a	8.2 ± 1.7A,b	3.0 ± 1.6AB,b	0.5 ± 0.4A,b

Mean within columns followed by the same upper case letter are not significant different at $P < 0.05$. Means within rows followed by the same lower case letter are not significantly different at $P < 0.05$ ($F = 8.72$; df = 2,151; $P = 0.0003$).

Results and Discussion

Simulated Warehouses. The analysis of variance for eggs laid by female *P. interpunctella* in simulated warehouse studies (Table 1) showed a significant difference among attract-and-kill formulations ($F = 8.72$; df = 2,151; $P = 0.0003$), among density of formulated devices assigned to rooms ($F = 28.37$; df = 3,214; $P < 0.0001$) and among density of moths ($F = 5.19$; df = 2,214; $P = 0.0063$). Only one device, either the wax panel or the plastic cylinder formulation, per room was needed to significantly suppress the egg laying at all densities of moths of *P. interpunctella* (5, 10, and 15 moth pairs per room, respectively) compared with untreated controls with no attract-and-kill device. The LastCall gel was the least effective, as it significantly impacted the egg laying only at the highest rate of three devices per room, and this was only for the lowest density of moths. However, three LastCall gel devices significantly suppressed egg laying at densities of 15 pairs of moths compared with untreated, but this treatment was similar statistically to treatments at one and two devices per room. One possible reason for the low impact on egg laying by LastCall gel at high population densities was that adult male moths were found stuck on the small surface of the gel drop, and thus may have prevented other males from contacting the gel and dying before mating. Another possible effect on treatments with low egg-laying was that freshly applied gel may have released large amounts of pheromone initially that repelled adult male moths instead attracting them (Campos and Phillips 2013), and such males may have been inhibited to mate females. Apparent effectiveness of the LastCall gel at the lowest moth density tested by Nansen and Phillips (2004), one male and one female, probably resulted from the single male in most replicates

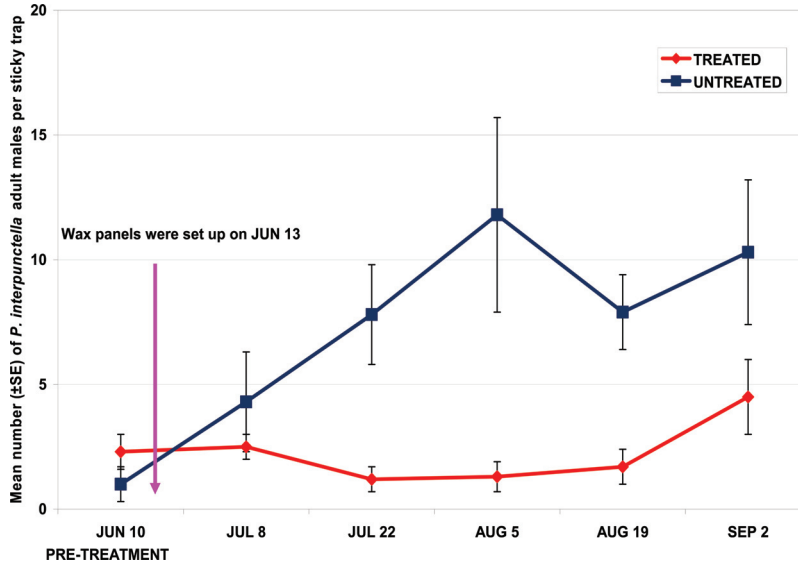

Fig. 1. Mean number (±SE) of *P. interpunctella* adult males per sticky trap in treated and untreated commercial buildings in the Dallas, TX, area in 2005. Treated buildings had the attract-and-kill formulation of wax panels impregnated with permethrin at 6% a.i. deployed with a synthetic female sex pheromone Biolure. Treatment comparisons with a "*" are significantly different at $P < 0.05$ ($F = 18.73$; df = 1,8.2; $P = 0.0024$). (Online figure in color.)

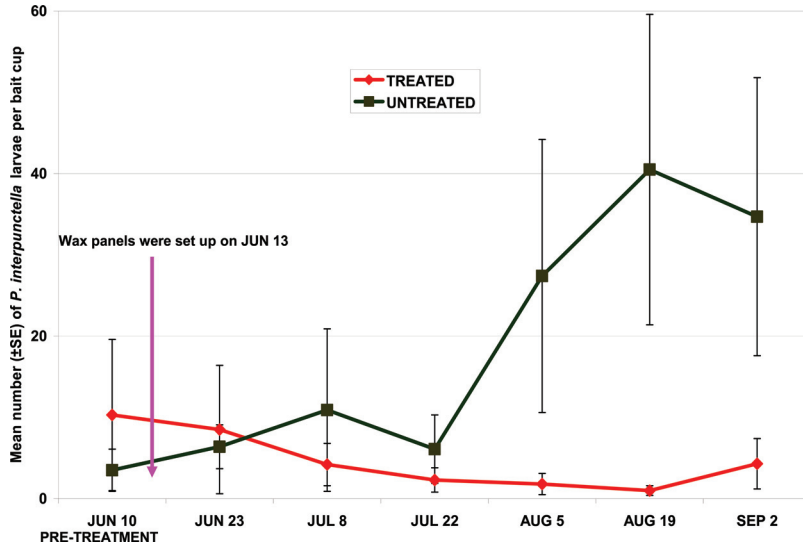

Fig. 2. Mean number (±SE) of *P. interpunctella* larvae per bait cup in treated and untreated commercial buildings in the Dallas, TX, area in 2005. Treated buildings had the attract-and-kill formulation of wax panels impregnated with permethrin at 6% A.I. deployed with a synthetic female sex pheromone Biolure. Treatment comparisons with a "*" are significantly different at $P < 0.05$ ($F = 5.20$; df = 1,6.47; $P = 0.0597$). (Online figure in color.)

being intoxicated after contact with the gel, which preceded his finding the female to mate.

Field Experiments. The mean number of *P. interpunctella* adult males per sticky trap is shown in Fig. 1 for the 2005 experiment. There were clear statistical difference between the attract-and-kill wax panel and untreated within weeks ($F = 18.73$; df = 1,8.2; $P = 0.0024$). Trapping on 10 June, which was the pretreatment period, was not significantly different between the buildings destined to have wax panels and the untreated control buildings, and this similar lack of difference was observed through 8 July. However, from 22 July until the end of the experiment (2 September), the buildings with wax panels had significantly lower male moth captures in pheromone traps compared with untreated buildings.

Fig. 2 shows the mean number of larvae per bait cup for the 2005 experiment. The overall difference between treatments for the experiment was very close to being biologically significant ($F = 5.20$; df = 1,6.47; $P = 0.0597$). Analysis of each week separately found that treatments were similar statistically from 10 June through 22 July, but from 5 August to the end of the experiment the number of larvae present in the bait cups in treated establishments was significantly lower than those from cups in untreated establishments. The results for 2005 suggest that the wax panel treatment effectively suppressed *P. interpunctella* populations ≈1–2 mo after application.

The increase of the *P. interpunctella* populations in the food establishments resulted from the movement of infested merchandise into the establishments and probably more so from normal increases owing to reproduction in warm weather with ample food. However, the densities of these insects were suppressed in buildings treated with wax panels compared with the control buildings that displayed population increases.

For the 2006 experiment, the mean number of *P. interpunctella* adult males captured is shown in Table 2. There was a significant experiment-wide difference among treatments ($F = 5.52$; df = 3,17.7; $P = 0.0074$) and weeks ($F = 4.11$; df = 7,75.9; $P = 0.0007$), but there was not an influence of the week over the treatments ($F = 1.57$; df = 21,74; $P = 0.0824$). The pretreatment monitoring was made at weeks 0 and 2 (2 and 16 June of 2006). At week 0, there were no significant differences among treatments, and at week 2, the buildings destined to be set up with the attract-and-kill method

Table 2. Mean number (±SE) of *P. interpunctella* adult males per sticky trap caught in several pheromone-based methods of control in commercial establishments in Dallas, TX, 2006

Treatment	2 June 2006 Week 0	16 June 2006 Week 2	30 June 2006 Week 4	16 July 2006 Week 6	28 July 2006 Week 8	11 Aug. 2006 Week 10	25 Aug. 2006 Week 12	2 Sept. 2006 Week 14
Attract-and-kill	3.6 (±1.8)a	7.3 (±2.3)a	5.1 (±1.0)a	2.9 (±0.6)a	5.6 (±1.5)a	4.3 (±1.4)a	5.7 (±1.2)a	4.2 (±0.5)a
Mass trapping	0.6 (±0.5)a	1.8 (±0.7)b	0.5 (±0.2)b	0.2 (±0.2)a	0.2 (±0.1)b	0.3 (±0.2)b	0.3 (±0.2)b	0.5 (±0.1)b
Mating disruption	0.4 (±0.2)a	1.6 (±0.2)b	1.2 (±0.5)b	2.4 (±1.4)a	2.7 (±2.8)a	2.3 (±0.5)a	2.2 (±0.6)b	2.6 (±0.3)ab
Untreated	0.9 (±0.1)a	2.9 (±1.2)b	3.3 (±1.3)b	4.6 (±1.0)a	4.2 (±2.7)ab	4.3 (±4.1)a	4.1 (±1.7)ab	4.0 (±1.0)ab

Treatments were set up on June 19th, after Week 2. Means within columns followed by the same letter are not significantly different ($F = 5.52$; df = 3,17.7; $P = 0.0074$).

Table 3. Mean number (±SE) of *P. interpunctella* larvae per bait cup caught in several pheromone-based methods of control in commercial establishments in Dallas, TX, 2006

Treatment	16 June 2006 Week 2	30 June 2006 Week 4	16 July 2006 Week 6	28 July 2006 Week 8	11 Aug. 2006 Week 10	25 Aug. 2006 Week 12	8 Sept. 2006 Week 14
Attract-and-kill	3.4 (±1.4)a	5.4 (±2.9)ab	3.6 (±3.0)b	3.1 (±2.8)b	5.4 (±3.9)b	8.5 (±5.5)ab	3.7 (±2.1)b
Mass trapping	3.4 (±2.0)a	3.0 (±2.6)b	0.8 (±0.6)b	1.0 (±1.0)b	0.6 (±0.4)b	1.0 (±0.9)b	0.2 (±0.2)b
Mating disruption	7.8 (±4.0)a	0.0 (±0.0)b	1.5 (±1.5)b	0.0 (±0.0)b	8.3 (±6.4)ab	1.2 (±1.1)b	3.5 (±1.7)b
Untreated	7.9 (±4.6)a	13.0 (±5.4)a	13.9 (±7.1)a	16.9 (±7.8)a	15.9 (±6.1)a	13.9 (±4.9)a	15.1 (±6.5)a

Treatments were set up on June 19th, after Week 2. Means within columns followed by the same letter are not significantly different ($F = 7.62$; df = 3,16.4; $P = 0.0021$).

showed the higher number of adult males (7.3) caught per trap compared with all other rooms. Treatments were set up on June 19 of 2006. There were <0.5 adult males per sticky trap in the mass-trapping treatment during the whole experiment, which were numerically the lowest male numbers compared with the remainder of the treatments. However, numbers of males caught in mass-trapping buildings were not significantly different from those in mating disruption buildings, except in weeks 8 and 10. The attract-and-kill, mating disruption, and untreated did not show significant differences in male activity by the end of the study. One potential reason for the success of the wax panel attract-and-kill devices in 2005 compared with that of the plastic-coated paper panels in 2006 may be from the high concentration and amount of the active ingredient contact insecticide on the wax surface, making it a more effective and long-term killing substrate.

The mean number of *P. interpunctella* larvae per bait cup in the 2006 experiment is shown in the Table 3. There were significant differences among treatments ($F = 7.62$; df = 3,16.4; $P = 0.0021$), but there were no significant difference among weeks ($F = 0.28$; df = 6,60.7; $P = 0.9444$), nor was there influence of weeks (time) over the treatments ($F = 0.81$; df = 18,60.3; $P = 0.6858$). The pretreatment monitoring with bait cups was for one 2-wk period, ending 16 June of 2006, and there were no statistically significant differences. After deploying treatments the attract-and-kill, mass-trapping and mating disruption methods were not significantly different from each other, for the most part, but had significantly lower numbers of moth larvae in food cups compared with untreated controls in most weeks. The untreated establishments were statistically similar to the attract-and-kill buildings at week 4 and 12, and they were similar to the mating disruption at week 10. On these dates, the number of larvae was low in most samples, and this was possibly owing to the presence of the sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.) (Coleoptera: Sivanidae), which might be an egg predator, and also to the larval parasitoid *Bracon hebetor* (Hymenoptera: Braconidae), which were both found in cups on those dates.

The research reported here demonstrates the efficacy of pheromone-based attract-and-kill technology, as well as mating disruption and mass-trapping, for suppressing pest populations of *P. interpunctella.* Commercial formulations of mating disruption for stored-product moths are already available in the United States (Phillips and Throne 2010), but we are not aware of any registered products for storage moths that use synthetic pheromone in an attract-and-kill formulation. Mass trapping of lepidopteran pests has been known and successfully applied for various pest species (e.g., Lanier 1990), but one drawback of mass trapping in practice is the need for frequent trap servicing and the loss of effectiveness if traps, especially sticky traps, become saturated with trapped male moths and fail to trap subsequent males after saturation. Mating disruption does not kill males, but the inability of males to mate females is the desired result. Attract-and-kill results in male death with no concern like that of trap saturation, and can be as effective as mass trapping and mating disruption. Pheromone-based control methods represent species-specific techniques that can be implemented with little or no insecticide inputs and can be found preferable and perhaps more effective than traditional chemical insecticide treatments.

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