Attractancy and Toxicity of an Attracticide for Indianmeal Moth, *Plodia interpunctella* (Lepidoptera: Pyralidae)

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ABSTRACT *Plodia interpunctella* (Hübner) is a serious and widespread postharvest pest on cereal products, dried fruits, candy, and pet food. Due to the strong positive anemotactic flight response of *P. interpunctella* males to the main component of the female-produced pheromone [(*Z*,*E*)-9,12-tetradecadienyl acetate, herein referred to as ZETA], we evaluated the potential of an attracticide for this pest, in which ZETA as attractant was combined with permethrin as the killing agent. Two concentrations of ZETA [0.16 and 0.32% (wt:wt)] and five concentrations of permethrin [0, 3, 6, 12, and 18% (wt:wt)] were incorporated into Last Call gel (10 different permethrin:ZETA combinations). All attracticide gels were evaluated in a toxicity test, in which either the tip of a leg or an antenna of a virgin *P. interpunctella* male was touched <3 s into a dot of attracticide gel. These males were subsequently transferred to jars with virgin females. The toxicity test showed that a brief and gentle contact of *P. interpunctella* males with attracticide gel containing 3–18% permethrin caused a significant reduction in mating and killed males moths within 24 h. A wind tunnel test was conducted to evaluate the flight responses of *P. interpunctella* males to the same 10 attracticide gels. Male moths displayed significantly higher levels of positive anemotactic flight and more males made contact with the attracticide gel when the ZETA concentration was 0.16% compared with 0.32%. *P. interpunctella* males showed no signs of repellency to permethrin concentrations within a range of 0–18% in the attracticide gel. Three densities of *P. interpunctella* pairs were released into small warehouse rooms, and we found that the attracticide gel suppressed oviposition when the moth density was at a low level, but it was ineffective when the moth density exceeded one male-female pair per 11.3 m^3.

KEY WORDS pheromone, stored-products, permethrin, attract-and-kill, oviposition

THE INDIANMEAL MOTH, *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae), is a widespread and serious pest on bulk-stored grain and seeds (Lecato 1976, Storey et al. 1983, Vick et al. 1986, Cuperus et al. 1990, Doud and Phillips 2000, Nansen et al. 2004), flour, feed and other milled products (Lecato 1976), prototype military rations (Cline and Highland 1985), dried fruits (Johnson et al. 1992), and nuts (Johnson et al. 1992). Damage of food products is attributed to feeding by larvae, which are capable of penetrating a wide range of packing materials (Cline 1978). Infestations by *P. interpunctella* can have a great economic impact due to direct product loss and indirectly to factors such as the cost of pest control and loss of sales from consumer complaints (Phillips et al. 2000a). The fumigant methyl bromide is widely used to control *P. interpunctella* and other stored-product pests in food processing and warehousing facilities, and the anticipated U.S. ban in 2005 of this fumigant has motivated research on alternative methods to control stored-product insect pests (Fields and White 2002).

Pheromone-baited sticky traps are widely used for early detection and monitoring of stored-product moth populations in and around food facilities, and the main component of the *P. interpunctella* female-produced pheromone [(*Z*,*E*)-9,12-tetradecadienyl acetate (Z9,E12–14:Oac, herein referred to as ZETA)] was identified by Brady et al. (1971) and Kuwahara et al. (1971), and ZETA was among the first pheromones to become commercially available (Phillips 1997). Later, three additional components of the *P. interpunctella* female-produced pheromone were identified (Kuwahara and Casida 1973, Sower et al. 1974, Soderstrom et al. 1980, Teal et al. 1995, Zhu et al. 1999) in the following relative ratio to 100 U of ZETA (Zhu et al. 1999): 1) (*Z*,*E*)-9,12-tetradecadienal (Z9,E12–14:Ald), 11 U; 2) (*Z*,*E*)-9,12-tetradecadienol (Z9,E12–14:OH), 18 U; and 3) (*Z*)-9-tetradecenyl acetate (Z9–14:Oac), 12 U. However, most commercial *P. interpunctella* lures only contain ZETA. The response of male moths to female-produced sex pheromone may also be used for suppression of these insect pests through either mating disruption or an attracticide (Phillips et al. 2000b). Mating disruption involves release of sex pheromone in high amounts to confuse male moths in their search for conspecific females and thereby reduce the frequency of mating (Cardé and

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Minks 1995). Mating disruption for stored-product moths has been evaluated for *Sitotroga cerealella* (Olivier) (Vick et al. 1978), *Ephestia cautella* (Walker) (Mafra-Neto and Baker 1996, Shani and Clearwater 2001), and *P. interpunctella* (Ryne et al. 2001). An attracticide involves combination of an attractant, typically a sex pheromone and/or a food odor, and a killing agent (pathogen or pesticide), so that the insects are attracted to a point source and subsequently killed after contact with the attracticide (Lanier 1990). Compared with traditional applications of pesticides, the main advantages of using an attracticide are 1) insecticides are not broadcast over large areas; 2) insecticides are not applied directly onto food materials; 3) nontarget insects (beneficials) are unlikely to be affected; and 4) although relatively high concentrations may be used in point sources, the total amount of pesticide needed to treat a facility is considerably smaller overall compared with a broadcast treatment. Efficient insect control based on attracticides has been shown for a number of important moth pests on forest trees [western spruce budworm, *Choristoneura occidentalis* Freeman (Sower and Shorb 1985)], field crops [pink bollworm, *Pectinophora gossypiella* (Saunders) (Haynes et al. 1986, Miller et al. 1990); Egyptian cotton leafworm, *Spodoptera littoralis* Boisduval (De Souza et al. 1992, Downham et al. 1995)], and fruits [navel orangeworm, *Amyelois transitella* (Walker) (Phelan and Baker 1987), codling moth, *Cydia pomonella* (L.) (Charmillot and Hofer 1997), and light brown apple moth, *Epiphyas postvittana* (Walker) (Brockerhoff and Suckling, 1999, Suckling and Brockerhoff 1999)]. Trematerra and Capizzi (1991) described the use of an attracticide to control the Mediterranean flour moth, *Ephestia kuehniella* Zeller.

In this study, we evaluated a commercially formulated attracticide for *P. interpunctella* in which ZETA was used as the attractant and the synthetic pyrethroid permethrin was the killing agent. Experiments were designed to determine 1) to what extent subtle contact of *P. interpunctella* males with the attracticide would affect their survival and ability to mate; 2) the positive anemotactic flight response of *P. interpunctella* males to the attracticide in a wind tunnel; and 3) the potential of the attracticide to suppress *P. interpunctella* populations under controlled, simulated warehouse conditions with different moth densities.

Materials and Methods

Insects. *P. interpunctella* adults from the laboratory culture at Oklahoma State University were reared in a growth chamber at a photoperiod of 16:8 (L:D) h, 28°C, and 60–70% RH on a standardized diet of corn meal, chick laying mash, chick starter mash, and glycerol at a volumetric ratio of 4:2:2:1, respectively. The light program of the growth chamber was set so that 8 a.m. corresponded to the beginning of the scotophase. Pupae were sexed and carefully transferred to individual 2-ml glass vials. All experiments were conducted with virgin adults that were 1–2 d old; adults were only used once.

Attracticide. A commercially developed attracticide gel formulation known as Last Call was used and prepared for us as needed by the manufacturer (IPM Technologies Inc., Portland, OR). We examined five concentrations of permethrin [0, 3, 6, 12, and 18% (wt:wt)] and two concentrations of ZETA [0.16 and 0.32% (wt:wt)[rsqb] (total of 10 attracticide gels). In all experiments, we used individual attracticide gel dots that weighed 0.015 ± 0.005 g.

Toxicity Test. Individual *P. interpunctella* males were held with "feather weight" forceps (BioQuip, Rancho Dominguez, CA), and a single leg or antenna was dipped gently into a dot of attracticide for <3 s. All 10 attracticide gels were examined, and 10 *P. interpunctella* males were tested individually for each attracticide gel. Immediately after the forced contact with the attracticide, each male was transferred to a 250-ml glass jar containing 15 g of whole wheat kernels and a virgin *P. interpunctella* female. After 24 h, the whole wheat kernels were sifted, the number of eggs laid was counted, and the status of the male was evaluated and assigned a score as follows: dead, 0; immobile but alive, 1; and alive, 2. Virgin females lay eggs if they are kept for 4–5 d (C.N., unpublished data), so a control group of 10 jars with wheat was set up in which a single virgin female was kept under the same conditions for 24 h without introducing a *P. interpunctella* male.

Wind Tunnel Experiment. The flight response of *P. interpunctella* males to the attracticide was examined in a wind tunnel (square cross section of 0.9 by 0.9 m, 1.8 m in length), typical of those used for moth flight bioassays (Haynes and Baker, 1989). An aluminum mesh screen was mounted in front of the fan to keep insects inside the wind tunnel. Room air entered the wind tunnel through a screen filter impregnated with activated carbon at the upwind end, and air was pulled through the tunnel and exhausted out of the room by an electric fan mounted equidistant from the tunnel sides in a sheet-metal reduction plenum. The wind tunnel and air in the room housing it were kept at 18–22°C and 30–40% RH, respectively. The airflow rate inside the tunnel was ≈10 cm/s. A 10 by 10-cm platform was placed 30 cm from the flight tunnel floor in the upwind end and was used to hold a microscope slide with a dot of attracticide gel, which was introduced into the wind tunnel 15 min before the flight response of the first *P. interpunctella* male was evaluated. Attracticide gel dots were replaced after every four to five trials. In the downwind end of the wind tunnel 30 cm from the floor in front of the fan, individual *P. interpunctella* males were released from a cylindrical screened release cage (5 cm in diameter and 4 cm in height), which was placed on a metal platform.

P. interpunctella males were tested individually, and they were kept inside the release cage for preconditioning for 5 min before release. Experiments were conducted under dim lighting during morning and afternoon hours. The following behavioral responses,

similar to those used by Haynes et al. (1986), were recorded: 1) wing fanning in the release cage during preconditioning was scaled from 0 to 3 with 0 being no fanning and three being intensive fanning; 2) take-off (yes/no); 3) time spent at release platform before take-off; 4) positive anemotactic flight (yes/no); 5) landing on the platform holding the attracticide (yes/no); 6) time of flight from release until landing on the platform; 7) direct contact with the attracticide dot (yes/no); and 8) the type of contact with the attracticide was scaled from 0 to 3 of *P. interpunctella* males that landed on the platform: 0, no touch; 1, gentle touch with either a single leg or with just one antenna; 2, touch with at least two body parts (e.g., two legs, one leg, and an antenna) or touch with a wing; and 3, when the male either crossed the attracticide gel dot by walking over it, got stuck in the gel, or in other ways had distinct or prolonged contact with the attracticide gel. A trial was terminated within a maximum of 15 min. We evaluated the flight response of 7–10 *P. interpunctella* males for each attracticide gel on two separate days (a total of 15–20 males per attracticide gel). A weak soap solution was used to clean the wind tunnel between bioassays with different attracticide gels.

Suppression Study. Three metal storage sheds (Piedmont, Mauldin, SC), each of 11.3 m^3 [2.3 m (width) by 3.0 m (length) by 1.7 m (height)], were used as simulated warehouses for evaluation of the attracticide gel. The efficacy of the attracticide gel was determined by comparing oviposition by *P. interpunctella* in three storage sheds with the following simultaneous treatments: 1) one freely exposed attracticide gel dot was applied to a paper card placed on the center of the south wall in the storage shed; 2) an attracticide gel dot was similarly applied to the south wall in another storage shed, but a screen cage (1.2-mm mesh opening) was mounted around the attracticide to allow the males only to come within a 2-cm range of the gel dot; and 3) no gel dot (control). Oviposition was assessed by counting the total number of eggs laid by *P. interpunctella* females in three petri dishes in each storage shed (10 cm in diameter), each containing 10 g of whole wheat kernels treated with walnut oil (10 μl/g wheat kernel). Nansen and Phillips (2003) determined that whole wheat kernels treated with this concentration of walnut oil stimulated oviposition by *P. interpunctella* females. The three food dishes were placed on a wooden shelf (60 by 120 cm) suspended in the center of the storage shed 70 cm above the ground. The suppression studies were conducted during winter (December 2002–April 2003), and an electric heater was placed underneath the wooden shelf in each of the three storage sheds to maintain the temperature between 25 and 30°C and 30–40% RH (monitored with Hobo data logger in each storage shed). Based on the results from the toxicity test and the wind tunnel experiment, we evaluated the attracticide gel containing the combination of 6% permethrin and 0.16% ZETA in the suppression study. The suppression study was conducted in complete darkness. For each replication, the three treatments were changed randomly among the storage sheds, and compressed air was used to clean the walls inside the storage sheds between subsequent trials. Each trial lasted 76 h and was repeated six times. Pairs of moths were released in three densities (females:males): 1:1, 3:3, and 5:5.

Statistical Analysis. The PROC MIXED procedure with inbuilt contrasts in PC-SAS 8.0 (SAS Institute 1999) was used to examine the concentration effects of ZETA and permethrin on 1) the ovipositional response of *P. interpunctella* females mated to males in the toxicity test; 2) the behavioral flight response by males in the wind tunnel experiment; and 3) the ovipositional response (total number of eggs laid in the three food dishes per number of *P. interpunctella* females) in the suppression study in the simulated warehouses. The PROC NPAR1WAY in SAS was used to conduct a Kruskal–Wallis test with Wilcoxon scores of the concentration effects of ZETA and permethrin on 1) ranked male status after 24 h in the toxicity test; 2) ranked observations of fanning in the release cage, 3) binomial data on upwind flight response and landing on platform containing the attracticide; and 4) ranked observations of the male contact with dots of the attracticide.

Results

Toxicity Test. *P. interpunctella* females laid no or very few eggs during 24 h when no male was offered in control experiments (Fig. 1). In the PROC MIXED analysis of eggs laid, we found that forced male moth contact with permethrin had a significant effect on total oviposition by females ($F_{4,90} = 4.89$; $P < 0.01$), whereas ZETA concentration had no significant effect on the total oviposition ($F_{1,90} = 0.27$; $P = 0.61$). There was no significant interaction effect between permethrin concentration and ZETA concentration ($F_{4,90} = 1.26$; $P = 0.29$). Because there was no significant effect in toxicity caused by ZETA concentration, we grouped the results from 0.16 and 0.32% ZETA and contrasted oviposition results across permethrin concentrations (Fig. 1). There was no significant difference in oviposition when males had been exposed to attracticides containing 0 or 3% permethrin ($F_{1,90} = 1.07$; $P = 0.30$), but total oviposition was significantly lower when attracticides contained 6% permethrin compared with 3% ($F_{1,90} = 6.31$; $P = 0.01$). In the Kruskal–Wallis test of the ranked male status after 24 h, we found that permethrin concentration in attracticides had a significant effect on males status after 24 h ($\chi^2 = 64.04$, df = 4, $P < 0.01$), whereas ZETA concentration ($\chi^2 = 0.22$, df = 1, $P = 0.64$) did not have significant influence on the male status after 24 h (Fig. 2). Again, we grouped the results from 0.16 and 0.32% ZETA and made paired comparisons of the males' status at different permethrin concentrations. There was a significant difference in male status of treatments with 0 and 3% permethrin ($\chi^2 = 6.84$, df = 1, $P < 0.01$), and 3 and 6% permethrin ($\chi^2 = 15.7$, df = 1, $P < 0.01$), but there was no significant difference in

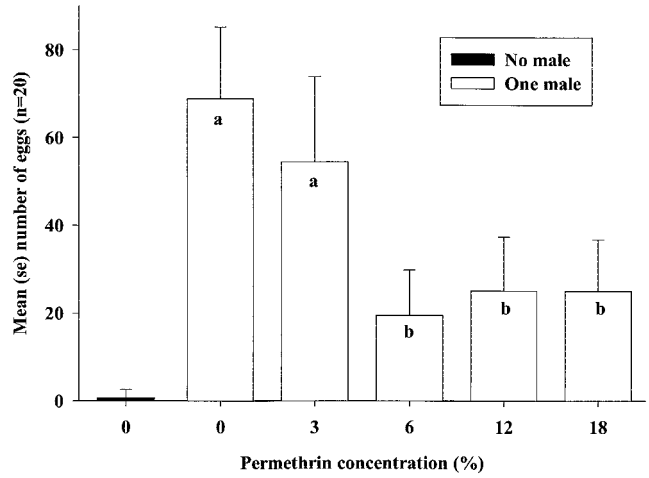

Fig. 1. Mean oviposition within 24 h of single *P. interpunctella* couples after the male had subtle contact with one of 10 attracticides containing 0.16 or 0.32% ZETA and 0, 3, 6, 12, and 18% permethrin. Results with different ZETA concentrations were grouped because only permethrin concentration had significant effect on oviposition (as indicated by different letters). Oviposition by females not paired with a male was not included in the statistical analysis.

male status for treatments with attracticides containing 6, 12, or 18% permethrin ($P > 0.05$).

Wind Tunnel Experiment. The flight responses of *P. interpunctella* males in the wind tunnel experiment are summarized in Table 1. Most of the tested *P. interpunctella* males performed considerable fanning during the preconditioning, and neither permethrin concentration ($\chi^2 = 8.26$, df = 4, $P = 0.22$) nor ZETA concentration ($\chi^2 = 0.13$, df = 1, $P = 0.72$) had significant effect on the scoring of fanning. All *P. interpunctella* males left the release cage and neither permethrin concentration ($F_{4,141} = 1.99$; $P = 0.10$) nor ZETA concentration ($F_{1,141} = 3.86$; $P = 0.06$) had significantly affect on the time the male moths stayed at the release platform before take-off. Significantly more *P. interpunctella* males performed upwind flight toward attracticide gels containing 0.16% ZETA ($n = 77$, 0.83 ± 0.04 [SE]) than to those containing 0.32% ($n = 74$, 0.63 ± 0.06) (df = 1, $\chi^2 = 7.40$, $P < 0.01$), but the proportion of males performing upwind flight was not affected significantly by the permethrin concentration ($\chi^2 = 5.52$, df = 4, $P = 0.24$) (Table 1). The proportion of upwind-flying *P. interpunctella* males landing on the platform with the attracticide was not affected by the permethrin concentration ($\chi^2 = 6.38$, df = 4, $P = 0.17$), but a significantly higher proportion of *P. interpunctella* males landed on the platform when the attracticide contained 0.16% ZETA ($n = 77$, 0.71 ± 0.05) compared with 0.32% ZETA ($n = 74$, 0.55 ± 0.06) ($\chi^2 = 4.16$, df = 1, $P = 0.04$) (Table 1). Flight time of

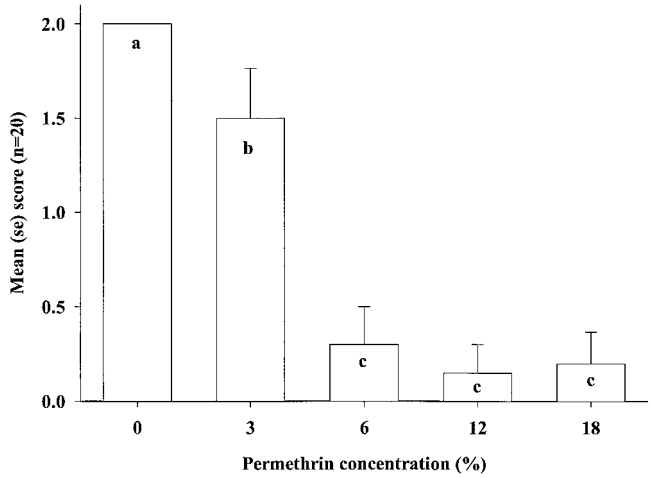

Fig. 2. Status of individual *P. interpunctella* males 24 h after exposure to 0.16 or 0.32% ZETA and 0, 3, 6, 12, and 18% permethrin. The status of the male was assessed according to the following scale: 0, dead; 1, immobile, and/or affected; and 2, alive and not affected (normal behavior). Results with different ZETA concentrations were grouped because only permethrin concentration had significant effect on male status (as indicated by different letters).

Table 1. Mean (SE) behavioral responses of *P. interpunctella* males in wind tunnel to attracticides with different pheromone and permethrin concentrations

ZETA	Permethrin	Fanning[a]	Take-off[b]	Upwind[c]	Landing[d]	Flight time[e]	Touch[f]
0.16	0	2.5 (0.13)	19.8 (7.7)	0.80	0.73	198.0 (55.2)	2.1 (0.18)
0.16	3	2.5 (0.21)	10.8 (1.9)	0.88	0.69	137.4 (45.1)	2.1 (0.29)
0.16	6	2.6 (0.16)	11.9 (1.7)	0.75	0.56	225.7 (67.5)	2.1 (0.27)
0.16	12	2.3 (0.16)	19.4 (5.2)	0.93	0.80	196.3 (37.1)	1.5 (0.23)
0.16	18	2.4 (0.19)	18.1 (5.4)	0.80	0.80	88.6 (22.2)	2.6 (0.24)
0.32	0	2.8 (0.11)	10.7 (2.6)	0.60	0.47	219.6 (67.1)	2.0 (0.21)
0.32	3	2.3 (0.13)	30.1 (12.1)	0.60	0.60	110.8 (21.8)	1.7 (0.18)
0.32	6	2.6 (0.13)	15.1 (3.1)	0.53	0.53	63.4 (22.2)	2.3 (0.12)
0.32	12	2.5 (0.13)	54.3 (22.8)	0.47	0.33	49.2 (10.2)	1.8 (0.12)
0.32	18	2.1 (0.16)	27.5 (8.3)	1.00	0.86	196.8 (49.3)	1.2 (0.27)

[a] Fanning during preconditioning was scored from 0 (no fanning) to 3 (intensive fanning).
[b] Time in seconds before the male left the release cage.
[c] Proportion of males performing upwind flight.
[d] Proportion of flying males that arrived at the platform holding the attracticide.
[e] Total flight time in seconds.
[f] Score for touch with the attracticide: 0, no touch; 1, gentle touch with either a single leg or with just one antenna; 2, touch with at least two body parts (e.g., two legs, one leg and an antenna) or touch with a wing; and 3, substantial or prolonged contact with the gel.

those landing on the attracticide platform did not vary significantly with neither permethrin concentration ($F_{4,85} = 0.71$; $P = 0.59$) nor ZETA concentration ($F_{1,85} = 1.27$; $P = 0.26$). The scoring of the male's contact with the attracticide revealed no significant effect of permethrin concentration ($F_{4,85} = 0.79$; $P = 0.53$) but was significantly higher when the attracticide contained 0.16% ZETA ($n = 54$, 2.07 ± 0.13) compared with 0.32% ZETA ($n = 41$, 1.71 ± 0.13) ($\chi^2 = 5.07$, df = 1, $P = 0.02$).

Suppression Study. Results from the toxicity test revealed no significant difference in toxicity when permethrin concentration was at least 6%, and the wind tunnel experiment indicated stronger and more complete anemotactic flight response to the attracticides containing 0.16% ZETA compared with those containing 0.32%. Consequently, we decided to use the attracticide containing 6% permethrin and 0.16% ZETA for the suppression study in storage sheds. When all trials (three moth densities × three treatments × six replications) were included in the analysis, there was no significant difference in mean number of oviposited eggs per *P. interpunctella* female for the three attracticide treatments ($F_{2,49} = 1.31$; $P = 0.29$), but the mean number of eggs oviposited per female decreased significantly with increasing moth density ($F_{2,49} = 4.60$; $P = 0.01$). Due to the apparent effect of moth density, we conducted a pairwise one-way analysis of variance (ANOVA) to examine treatment effect within each of the moth densities separately, and we found a significant effect of attracticide treatment. At the lowest moth density, the number of eggs laid per female was significantly lower for the trials with one exposed attracticide gel dot compared with control trial (no attracticide) ($F_{11} = 10.64$; $P < 0.01$), whereas there was no significant difference between trials with one screened attracticide gel dot and control ($F_{11} = 1.95$; $P < 0.19$) (Fig. 3). There was no significant difference in the number of eggs laid per female among the treatments for moth densities of three and five mating pairs per storage shed ($P > 0.05$).

Discussion

The toxicity tests in this study demonstrated that a brief and gentle contact with the attracticide containing at least 3% permethrin affects male survivorship and immediate ability to perform courtship behavior and successful copulation. Nevertheless, some mating may have occurred with intoxicated males before their deaths because more eggs were laid in these jars than in jars with unmated females. The glass jars used for these experiments represent highly constrained environments, in which the time needed to search for a mating partner was reduced to a minimum due to the small search area. Hence, mating could theoretically occur within a few minutes after *P. interpunctella* males had been exposed to the attracticide. Other work has documented that *P. gossypiella* males can recover and locate sex pheromone sources 2–4 d after a sublethal poisoning with an attracticide (Haynes et al. 1986), but we found that permethrin concentrations ≥6% killed most of the *P. interpunctella* males within a 24-h period. Our current study did not examine the longevity of permethrin activity after aging, and such work is needed before a recommendation on a specific permethrin concentration can be made for an attracticide that may be required to kill insects over several weeks in a practical application.

The results here, and those from a similar study (Phillips 1994), indicate that relatively higher doses of ZETA released from a point source elicit fewer contacts with the source by responding males compared with lower doses. Responses of male Lepidoptera to synthetic sex pheromones can be affected by, among other variables, relative concentrations and composition of the materials released from a point source (Cardé and Baker 1984). Although up to four separate sex pheromone components have been identified from *P. interpunctella* females (Zhu et al. 1999), we

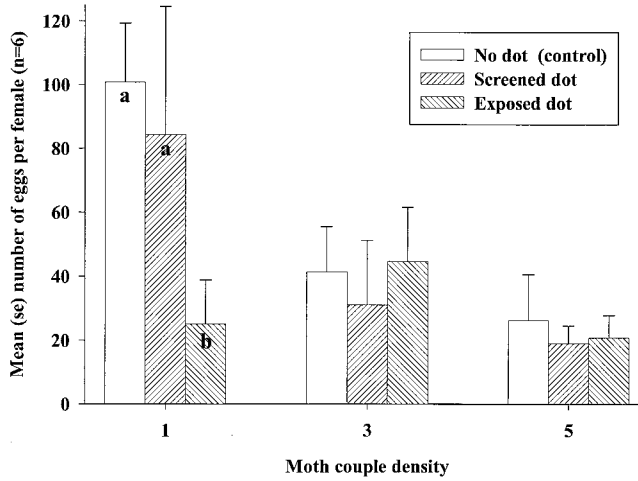

Fig. 3. Three densities of *P. interpunctella* (females:males: 1:1, 3:3, and 5:5) were released and oviposition in food dishes was assessed after 76 h in storage sheds with three different treatments: 1) one 0.015-g freely exposed gel dot of 6% permethrin and 0.16% ZETA was applied to the center of the south wall in the storage shed (dot exposed); 2) one screened gel dot of was applied to the center of the south wall in the storage shed (screened dot); and 3) control (no dot). Different letters among treatment indicate significant difference in number of eggs oviposited in food dishes at the lowest moth density.

used only the predominant compound, ZETA. *P. interpunctella* males respond with a more complete sequence of orientation and mating behaviors to blends of pheromone compounds compared with ZETA alone (Vick et al. 1981, Zhu et al. 1999). Thus, it is possible that a higher efficacy of a *P. interpunctella* attracticide could be obtained in future work by using the four-component pheromone blend instead of ZETA alone. Furthermore, if ZETA only were to be used in practice for an attracticide, the formulation that would deliver an optimal release rate over a given time period for service would need to be determined.

We showed that the flight response of *P. interpunctella* males to the attracticide was unaffected by a permethrin concentration up to18%. Based on recommendations from the manufacturer of the attracticide gel (IPM Tehnologies Inc.), it was not recommendable to increase the permethrin concentration beyond 18% because this would substantially affect the physical characteristics (e.g., stickyness) of the gel. Haynes et al. (1986) found no evidence of reduction in upwind flight responses and source contact of *P. gossypiella* males when 1 and 10% of either cypermethrin, permethrin, or fenvalerate were added to an attracticide pheromone source in attracticide studies, but Phelan and Baker (1987) found that a 1% concentration of either cypermethrin or permethrin did reduce the flight responses of female *Ameyelois transitella* (Lepidoptera: Pyralidae) in similar wind tunnel tests. Fairly small dots of attracticide were used in our current study (15 mg), so it is possible that repellency to permethrin would have been detected if larger dots had been used.

Control tactics based on mass-killing of male insects will generally be more effective at lower population densities (Lanier 1990). Hence, suppression of male moths at high densities with attracticide may have only limited effect on the total population because remaining males tend to compensate by increasing their number of matings (Brower 1975). We found that when the moth density is one moth pair per 11.3 m^3, significantly fewer eggs were laid in the simulated storage sheds with a freely exposed attracticide gel dot compared with the oviposition in storage sheds with a caged dot of attracticide or control (untreated) storage sheds. Because one attracticide gel dot per 11.3 m^3 deployed under a moth-proof screen cage did not affect oviposition compared with untreated metal buildings, this study suggests that mating disruption was not occurring at this amount of the major pheromone component we used in the formulation and this single dot density per 11.3 m^3. Rather, the results implicate the toxic effect of the permethrin acting directly on males that contacted the attracticide as the cause of reduced oviposition. The significant difference in total oviposition at different moth pair densities in the metal buildings was not easily interpreted, and it seems unlikely that three petri dishes of 10 g of oil-treated wheat kernels could be a limiting factor. Little is known about intraspecific competition of ovipositing *P. interpunctella* females, but Phillips and Strand (1994) found that more oviposition by *P. interpunctella* occurred on dishes of food contaminated with conspecific larval secretions than on uncontaminated food. However, it is not known whether eggs laid in wheat kernels are attractive to ovipositing *P. interpunctella* females as well.

This study with small storage sheds provides the baseline for similar controlled studies in larger structures with various moth densities and attracticide deployment schemes for further evaluation of the at-

tracticide as a suppression tool for *P. interpunctella* infestations.

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