Effects of Height and Adjacent Surfaces on Captures of Indianmeal Moth (Lepidoptera: Pyralidae) in Pheromone-Baited Traps

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ABSTRACT Diamond-shaped pheromone-baited traps are used widely in food storage and food processing facilities for monitoring of *Plodia interpunctella* (Hübner), and here we evaluated to what extent trap captures were affected by 1) vertical placement of traps, 2) deployment of a horizontal landing platform to the diamond-shaped pheromone trap, and 3) placement of traps either freely exposed or along a sidewall. In the small sheds (height 1.8 m), traps were placed in three heights and significantly highest trap captures were obtained near the ceiling. When the same experiment was conducted in a larger room (height 6 m) with traps at seven heights, highest captures were obtained at both the lowest and highest traps. In a subsequent experiment, we deployed a horizontal platform to traps at seven heights and found that the importance of vertical placement became less important. Thus, it seemed that male moths preferred to orient to a pheromone source associated with a physical surface, such as the floor, ceiling, or landing platform. In a comparison of *P. interpunctella* male trap captures in a completely dark room (no visual cues), traps with a landing platform caught significantly more than traps without the platform. In a final experiment, we evaluated the effect of hanging traps either freely or adjacent to sidewalls, and significantly highest trap captures were obtained along side-walls. The results presented here suggest that deployment of a horizontal platform reduces the importance of the vertical placement of traps and seems to increase the trap efficiency, and we recommend placement of traps along sidewalls and/or near the ground.

KEY WORDS integrated pest management, monitoring, pheromone, stored-products, trap efficiency

DEVELOPMENT AND IMPLEMENTATION OF effective integrated pest management (IPM) strategies in retail stores, food warehouses, and food processing facilities relies heavily on the best information possible about the current status of food products and spatiotemporal fluctuations in insect population densities (Phillips et al. 2000a). Direct sampling procedures have not been developed for retail stores, food warehouses, and food processing facilities, but pheromone-baited traps are frequently used for monitoring and detection programs in these environments. Pheromone-baited traps are easy to handle, fairly inexpensive, and provide specific information about the flight activity of a few targeted species (for review, see Phillips et al. 2000b). However, interpretation of trap captures and how they are related to the population density of stored-product insects is hampered by numerous factors, such as, density of traps (Nansen et al. 2003), trap type (Levinson and Hoppe 1983, Barak et al. 1990, Mullen 1992, Quartey and Coaker 1992, Hussain et al. 1994, Mullen et al. 1998, Mullen and Dowdy 2001, Nansen et al. 2004b), visual cues on traps (Quartey and Coaker 1992), pheromone dosage in lures (Vick et al. 1986, Hussain et al. 1994, Nansen and Phillips 2004), pheromone composition (Phelan and Baker 1986, Zhu et al. 1999), air movement (Quartey and Coaker 1992), and trap height (Vick et al. 1986, Nansen et al. 2003, 2004a). The importance of trap height has been studied for a number of important pyralid field pests, such as millet stem borer, *Coniesta ignefusalis* (Hampson) (Youm and Beevor 1995); European corn borer, *Ostrinia nubilalis* (Hübner) (Derrick et al. 1992, Bruck and Lewis 1998); pickleworm, *Diaphania nitidalis* (Stoll) (Valles et al. 1991); and almond moth, *Cadra cautella* (Walker) (Ahmad 1987). In a comparison of trap captures of *C. cautella* (Walker) and *P. interpunctella* inside food warehouses, Vick et al. (1986) found no significant difference in trap captures at 2, 5, and 10 m. In one of few comprehensive references with practical information on how to use pheromone-baited traps in stored-product environments, Mueller (1998) recommended that pheromone-baited traps for stored-product insects are placed ≈2 m above the ground and that vertical beams and/or pallet racking in the facility are

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used as support for pheromone-baited traps. Although there are several practical reasons for placing pheromone-baited traps 2 m above the ground, we are unaware of any research studies in stored-product environments that support this recommendation.

P. interpunctella is a fully domesticated cosmopolitan pest in grain and grain products in bins (Cuperus et al. 1990, Vela-Coiffier et al. 1997, Nansen et al. 2004b), pet stores (Roesli et al. 2003), retail grocery stores (Platt et al. 1998, Arbogast et al. 2000), food warehouses (Vick et al. 1986, Campbell et al. 2002), food processing facilities (Bowditch and Madden 1996, Zhu et al. 1999, Doud and Phillips 2000), dried fruit facilities (Johnson et al. 2002),, and bakeries. The main component of the female-produced pheromone [(*Z,E*)-9,12-tetradecadienyl acetate (Z9,E12–14:Oac) (Brady and Nordlund 1971, Brady et al. 1971, Kuwahara et al. 1971, Kuwahara and Casida 1973), here referred to as ZETA] was among the first pheromones to become commercially available (Phillips 1997), and the positive anemotactic flight response of *P. interpunctella* males to ZETA is well-documented. An informal survey among some of the largest companies involved in commercialization of pheromone-baited traps in the United States found that pheromone traps and lures for *P. interpunctella* represent the bulk of the multimillion dollar annual market for pheromones of stored-product pests. Taking into account that 1) the flight behavior of pyralid pests has been studied intensively both under controlled laboratory conditions and in stored-product facilities, 2) vertical placement of traps has been shown to be important for other pyralid pests (see references above), 3) ZETA has been commercially available for >30 yr, and 4) pheromone-baited traps for monitoring of *P. interpunctella* represent a substantial economic value, it is somehow surprising that very little is known about the effect of vertical placement of such traps for this insect pest.

In this study, we evaluated captures of *P. interpunctella* males in pheromone-baited traps in trials with simultaneous trapping in different heights and with traps either hanging freely or adjacent to various types of physical surfaces. We also evaluated the importance of modifying the most commonly used traps for monitoring of this insect, the diamond-shaped sticky traps, by adding a horizontal landing platform.

Materials and Methods

Insects. *P. interpunctella* adults from the laboratory culture at Oklahoma State University were reared at a photoperiod of 16:8 (L:D) h, 28°C, and 60–70% RH on a corn meal-based diet (Phillips and Strand 1994).

Trapping Environments. Trials in experiment 1 were conducted inside three metal storage sheds (Piedmont, Mauldin, SC), each of 11.3 m^3 [2.3 m (width) × 3.0 m (length) × 1.7 m (height)] erected in a climate-controlled warehouse. The sheds were sealed with isolation foam in crevices and cracks to prevent *P. interpunctella* males from escaping. All trials in the storage sheds were conducted in complete darkness and without presence of food. Experiments 2, 3, and 5 were conducted in the multipurpose room of the Stored Products Research and Education Center (SPREC) at Oklahoma State University (13 m in width by 20 m in length by 6 m in height). The sidewalls in the multipurpose room were 3 m in height and the ceiling reached a height of 6 m from the ground in the center of the room. Wheat and corn were occasionally stored in the room, but it was predominantly used for storing equipment and machinery. The multipurpose room had constant artificial light from one source on the ceiling, and no attempt was made to control daylight that entered through windows in two doors. Also, there was considerable daytime human activity in the multipurpose room during the course of the experiments. So, in many ways the multipurpose room was similar to conditions in a real food warehouse. Experiment 4 was conducted in two empty rooms (3 m in width by 4 m in length by 2 m in height) in a building in which windows and doors had been sealed to maintain complete darkness and no food was present. Environmental conditions for all experiments varied from 25 to 29°C and 40–60% RH, but they were essentially constant for any given replication.

Traps and Lures. In all experiments, we used diamond-shaped Pherocon-II sticky traps (Trécé Inc., Adair, OK) intended to capture flying insects. In experiments 2, 3, and 4, a piece of double-faced corrugated cardboard (20 cm in width by 30 cm in length) was attached to one side on the bottom of sticky traps as a horizontal landing or orientation platform. The top of the trap was attached to a string so that the landing platform was at the bottom in a horizontal position. In all experiments, trapped *P. interpunctella* males were removed from the sticky interior of traps between replicates, and traps were replaced when >20 *P. interpunctella* males had been caught in a trap. Due to the relative small size of storage sheds in experiment 1, we prepared low-dosage lures by adding 100 μl of 1 μg of ZETA in 1 ml of hexane to each rubber septum (Sleeve stoppers, catalog no. 03-215-5, Fisher, Pittsburgh, PA), whereas in all other experiments 500 μl of 1 mg of ZETA in 1 ml of hexane was added to rubber septa lures.

Experiment 1: Vertical Captures in Small Storage Sheds. The purpose of this experiment was to evaluate the importance of vertical placement of sticky traps in a small (metal storage sheds) and dark environment and to determine to what extent moths would be captured in traps without a pheromone lure. In each storage shed, pheromone-baited traps were placed at three heights: ground level and 1 and 1.6 m above ground on two strings 2 m apart (six traps per storage shed). For each height, the position of the trap with the lure and without the lure was randomly selected by flipping a coin. A known number of *P. interpunctella* males (1–9 moths per storage shed per trial) was released in 25 replications, and trap catches were determined after 24 h.

Experiment 2: Vertical Captures in Large Multipurpose Room. The purpose of this experiment was to evaluate the importance of the vertical placement of sticky traps in a large environment (SPREC multipurpose room) with characteristics similar to a food warehouse. We placed three strings ≈8–10 m apart, at least 3 m from any sidewall, and pheromone-baited sticky traps were placed at 1-m intervals from the ground level, essentially resting on the floor, up to 6 m, which was directly underneath the ceiling in the highest part of the storage room. Separate trials were conducted in which all 21 traps were either with or without a horizontal platform. At the beginning of each trial, an unknown number of *P. interpunctella* adults of both sexes and of varying age was released inside the storage room at two separate locations about equal distance from the three vertical string with traps. By releasing mixed populations of *P. interpunctella* individuals, we expected to simulate a natural demographic distribution of moth populations in food warehouses and food processing facilities. The trap catches were determined after 3–4 d of trapping in all 21 sticky traps (3 strings × 7 heights), and 13 replications were conducted.

Experiment 3: Vertical Captures in Traps with and without Platform. The purpose of this experiment was to compare the relative effect of height and deployment of a rectangular platform to the bottoms of pheromone-baited sticky traps. We used the same facility and experimental procedure as in experiment 2, but here we used six vertical strings, each with seven sticky traps at 1-m vertical intervals, and 12 replications of 3–4 d each were conducted. For each trap position, a coin was tossed for random assignment of a landing platform to that trap.

Experiment 4: Captures with and without Platform in Darkness. The purpose of this experiment was to evaluate the importance of adding a rectangular platform to the bottoms of pheromone-baited sticky traps for orientation of *P. interpunctella* males in a completely dark environment. Two pheromone-baited sticky traps were placed at equal distances from the sidewalls, ≈1.5 m apart, and 1.5 m from the floor, in the two empty rooms of a separate building. For each trial, a coin was flipped to determine which of the two traps received the platform. An undetermined number of mixed age and mixed sex *P. interpunctella* adults was released from one location in each room for each replicate, and 15 replications of 3–4 d each were conducted.

Experiment 5: Vertical Captures along Surfaces and in Free Air. The purpose of this experiment was to evaluate the importance of placing pheromone-baited traps on a string positioned within 15 cm of a sidewall compared with traps hanging freely exposed ≈2 m or more away from the wall in a large room. We used three pairs of vertically arranged traps on strings such that one string in a pair was adjacent to a wall and the other string in the pair was at least 2 m away from the wall. Traps were placed at 0 (floor), 1, 2, and 3 m above the ground, so each trial included 24 traps (three pairs × four heights × two treatments). An unknown number of *P. interpunctella* individuals of both sexes and of varying age was released at two locations before each of nine replications of 3–4 d each.

Statistical Analysis. In all experiments, a "trial" represents trap captures within a small storage shed (experiment 1), dark room (experiment 4), or in the multipurpose room (experiments 2, 3, and 5) for a given date, and the number of trap captures within each trial varied among experiments: experiment 1, $N = 6$; experiment 2, $N = 21$; experiment 3, $N = 42$; experiment 4, $N = 2$; and experiment 5, $N = 24$. In experiments 2, 3, and 5, the statistical analyses were based upon averages of trap captures for each height. Due to considerable variation in total trap captures per trial in all experiments, we used the PROC RANK procedure in PC-SAS 9.0 (SAS Institute, Cary, NC) to convert absolute trap captures per trial into ranked trap captures in ascending order. Subsequently, the PROC MIXED procedure with inbuilt contrasts was used to examine rank trap capture scores: 1) at different heights (experiments 1, 2, 3, and 5); 2) for traps with and without platform (experiments 3 and 4); and 3) for traps hanging either along a sidewall or freely on a vertical string (experiment 5).

Results

Experiment 1: Vertical Captures in Small Storage Sheds. Total trap captures per trial varied between one and nine male moths, and in total 125 *P. interpunctella* males were caught in the 25 trials. Only 3% of these were trapped in the unbaited sticky traps. There was a significant difference in ranked capture scores in baited traps at the three heights ($F_{2, 72} = 26.67$; $P < 0.001$) with significantly highest catches at 1.6 m, whereas there was no significant difference in captures at 0.6 and 1.2 m (Fig. 1).

Experiment 2: Vertical Captures in Large Multipurpose Room. Total trap captures per trial varied between 9 and 102 male moths, and in total 615 *P. interpunctella* males were caught in the 14 trials. The 21 trap captures in each trial were averaged for each height before being converted into rank scores. There was a highly significant difference in trap captures at different heights ($F_{6, 91} = 36.70$; $P < 0.001$) with trap captures at 0, 1, and 6 m being significantly higher than trap captures at the medium heights (Fig. 2a). The

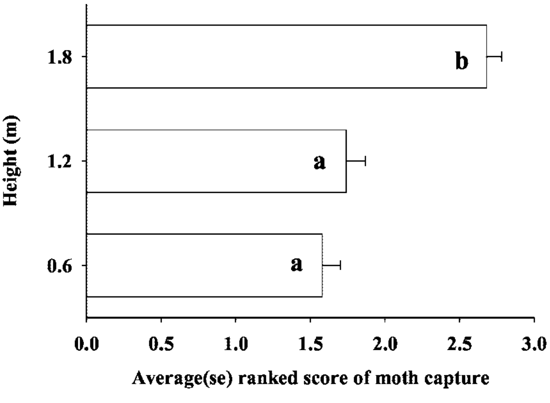

Fig. 1. Trapping of released *P. interpunctella* males with both unbaited and baited traps at three heights inside small storage sheds without presence of food. Letters represent significant difference in ranked trap capture scores ($P < 0.05$) ($N = 25$).

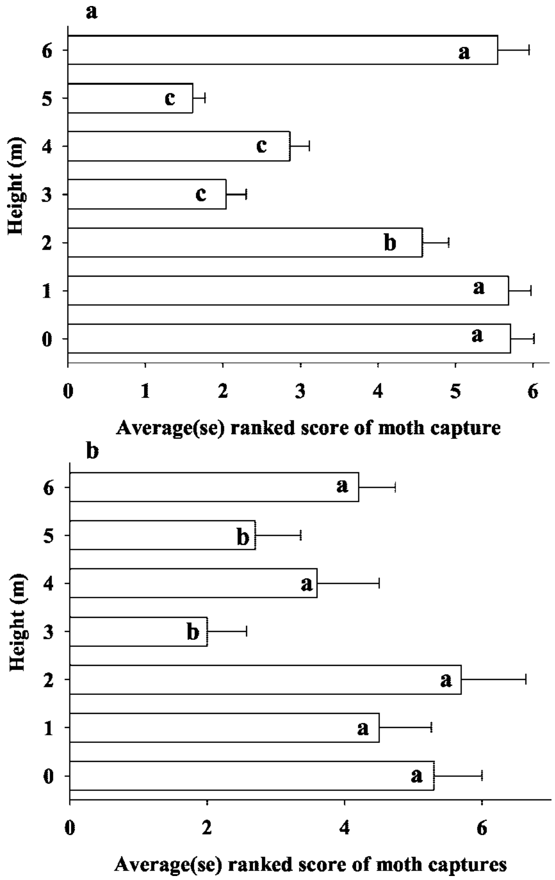

Fig. 2. Trapping of released *P. interpunctella* males with baited traps without horizontal platform (a) or with a horizontal platform (b) at seven heights inside a large multipurpose room with presence of food. Letters represent significant difference in ranked trap capture scores ($P < 0.05$) ($N = 39$).

same experiment was conducted but with all pheromone-baited traps having a horizontal platform, and we showed that 1) total trap captures per trial varied between 6 and 25 male moths, 2) in total 81 *P. interpunctella* males were caught in the five trials, and 3) there was a significant difference in trap captures at different heights ($F_{6, 28} = 3.27$; $P = 0.014$) with lowest trap captures of *P. interpunctella* males obtained 3 m above the ground. However, the addition of a horizontal platform seemed to affect the vertical distribution of trap captures, as very similar captures were obtained at heights 0–2 m from the ground and at four and 6 m above the ground (Fig. 2b).

Experiment 3: Vertical Captures in Traps with Platform. Due to the apparent effect of vertical placement of traps (experiments 1 and 2) and of deploying a horizontal platform to pheromone-baited traps (experiment 2), we intended to evaluate the relative importance of these two factors by randomly deploying horizontal platforms to traps at different heights. Total trap captures per trial varied between 40 and 67 male moths, and in total 365 *P. interpunctella* males were caught in the seven trials. The 42 trap captures in each trial were averaged per trap type (with and without platform) and height before being converted into rank scores, so rank scores ranged from 1 to 14. We found no significant difference in ranked trap capture scores for the two trap types ($F_{1, 84} = 3.21$; $P = 0.077$), but there was a significant difference in trap captures at seven heights ($F_{6, 84} = 6.33$; $P < 0.001$), and a significant difference in captures of trap types within heights (nested comparison) ($F_{6, 84} = 2.36$; $P = 0.037$) (Fig. 3).

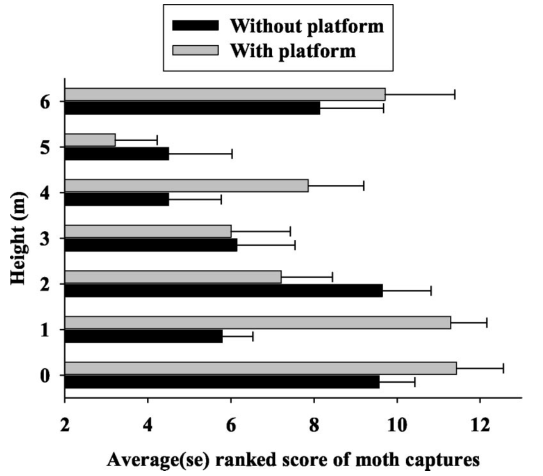

Fig. 3. Trapping of released *P. interpunctella* males with baited traps with or without a horizontal platform at seven heights inside a large multipurpose room with presence of food ($N = 27$).

Experiment 4: Captures with and without Platform in Darkness. Total trap captures per trial varied between 4 and 38 male moths, and in total 243 *P. interpunctella* males were caught in the 15 trials with paired traps in two totally dark rooms, and significantly highest trap captures in traps were with the horizontal platform ($F_{1, 28} = 15.75$; $P < 0.001$) (Fig. 4).

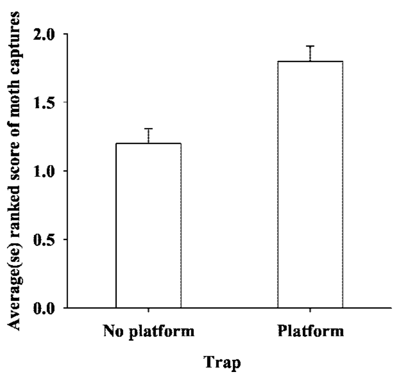

Fig. 4. Trapping of released *P. interpunctella* males with paired baited traps with or without a horizontal platform 1.5 m above the ground in a completely dark room. Letters represent significant difference in ranked trap capture scores ($P < 0.05$) ($N = 15$).

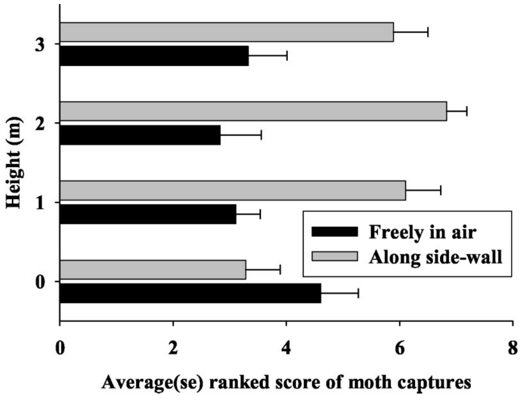

Fig. 5. Trapping of released *P. interpunctella* males with baited traps at four heights either placed along sidewalls or hanging freely on a vertical string inside a large multipurpose room with presence of food (N = 33).

Experiment 5: Vertical Captures along Surfaces and in Free Air. Total trap captures per trial varied between 27 and 83 male moths, and in total 477 *P. interpunctella* males were caught in the seven trials. The 24 trap captures in each trial were averaged per location (sidewall or hanging freely away from sidewalls) and height before being converted into rank scores, so rank scores ranged from 1 to 8. Ranked trap capture scores were significantly higher along sidewalls compared with those from traps hanging freely exposed on vertical strings ($F_{1, 64} = 23.56$; $P < 0.001$), whereas there was no significant difference in trap captures at different heights ($F_{3, 64} = 0.83$; $P = 0.484$), but we found a significant difference in captures along sidewalls or away from sidewalls within heights (nested comparison) ($F_{3, 84} = 7.62$; $P = 0.002$) (Fig. 5).

Discussion

Proper use of pheromone traps, and use of optimal traps designs, can be important in applications for spatial analysis and precision targeting of pest control. A recent study of the warehouse beetle, *Trogoderma variabile* Ballion (Coleoptera: Dermestidae), at 37 locations in a food warehouse, described how a fairly high number of pheromone-baited traps (>35) is required to make reliable predictions of the spatial distributions of stored-product pests in a two-dimensional plane (Nansen et al. 2003). The same study also highlighted that simultaneous trapping of the warehouse beetle at two different heights may indicate different levels of flight activity, so monitoring in three dimensions likely requires a much higher number of pheromone-baited traps.

Our analyses of pheromone-baited trap captures of *P. interpunctella* males in controlled experiments showed that very few moths were caught in traps without pheromone and, regardless of height, consistently more male moths were caught in pheromone-baited traps near surfaces. Results from the first experiment the small sheds initially suggested that moths would orient to the highest pheromone trap, but when traps without platforms were arrayed in the larger multipurpose room at seven heights the highest captures were at both the lowest and highest traps. The marked preference for either high or low traps was reduced, when a horizontal platform was deployed to traps at seven different heights. Thus, the addition of a horizontal platform clearly made the performance of the diamond shaped sticky trap less sensitive to their vertical position, although the results from experiment three suggested that the presence of a horizontal platform seemed to be less important than the vertical position of traps. In a direct comparison of traps with and without platform (experiment 4), significantly highest captures were obtained in traps with a horizontal platform even though this experiment was conducted in complete darkness. The final experiment with traps along side-walls again confirmed that male *P. interpunctella* prefer pheromone traps adjacent to surfaces.

In the detailed study of the courtship behavior of several pyralid moths, Phelan and Baker (1990) presented excellent drawings and descriptions of how the male pyralids fan and turn their wings and subsequently walk toward the female before initiating copulation. Thus, it seems that a landing platform, sidewall, floor, or ceiling would facilitate this courtship behavior and thereby improve the likelihood of *P. interpunctella* males being caught in the trap. Because the horizontal platform provides space for performance of certain courtship behavior, this may explain why significantly higher captures were obtained in traps with a horizontal platform than in those without a platform in complete darkness (experiment 4), and it also suggested that visual cues related to the platform were less important. Quartey and Coaker (1992) showed that trap captures of male pyralids were significantly higher in traps that were either: red, brown or black compared with blue, yellow, or white. Actually, lowest trap captures were obtained with white traps, although this is the most widely used color of commercially available sticky traps for these insect pests. Quartey and Coaker (1992) also showed that male pyralids responded significantly to striped patterns and that highest captures were obtained when the stripe width was 7.5 mm, whereas wider or narrower stripes reduced the trap efficiency.

In our experimental design, we conducted trapping at several heights simultaneously, and it may be argued that traps affected each other and that the effect of height should have been evaluated in independent trials with traps in one height at a time. However, with the current experimental design, traps at all heights were performing under similar conditions (assuming equal abiotic conditions within the vertical profile), which allowed us to make more reliable interpretations of where in a given sampling space the likelihood of catching a *P. interpunctella* male is highest. Whereas Vick et al. (1986) found no significant difference in trap captures of *P. interpunctella* males at 2, 5, and 10 m, Levinson and Hoppe (1983) showed that both males and female *P. interpunctella* preferred to land on suspended surfaces of certain shape and size and that drawings of certain geometric shapes on sticky cards were preferred over others, but pheromone was not included as a stimulus. Earlier studies by Levinson and Buchelos (1981) showed that a related stored product moth, *Ephestia kuehniella* Zeller, would fly to a pheromone source only when there was some light, but would not fly in total darkness. Mullen et al. (1998) noted that pheromone-baited traps close to walls captured more *P. interpunctella* than did traps located in the central parts of a room, but the role of trap height or the direct application of a larger trapping surface was not investigated.

Our study raises several practical considerations for the use and placement of pheromone traps in pest management programs for *P. interpunctella.* One might conclude that in large food facilities pheromone-baited traps for *P. interpunctella* males should be placed on the ground near a sidewall. However, one of the main arguments against placing traps on the ground is that they are more easily lost and damaged by human activity than are hanging traps (Nansen et al. 2003). Attachment of a horizontal platform seemed to increase the trap efficiency and also reduce the importance of the vertical placement of the trap, so that direct comparison of traps placed at different height within a facility may be more appropriate than for traps without the horizontal platform. Thus, we encourage pheromone-trap producers to consider deployment of a landing platform in more depth when designing new traps and also to consider the effects of color, shape, and pattern, because results published elsewhere suggest that the current white diamond-shaped trap may not be the most efficient trap design.

Acknowledgments

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