Activity of *Plodia interpunctella* (Lepidoptera: Pyralidae) in and Around Flour Mills

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ABSTRACT Studies were conducted at two flour mills where male Indian meal moths, *Plodia interpunctella* (Hübner), were captured using pheromone-baited traps. Objectives were to determine the distribution of male *P. interpunctella* at different locations in and around the mills throughout the season, and to monitor moth activity before and after one of the mills was fumigated with methyl bromide to assess efficacy of treatment. Commercially available sticky traps baited with the *P. interpunctella* sex pheromone were placed at various locations outside and within the larger of the two mills (mill 1). Moths were captured inside mill 1 after methyl bromide fumigations. The highest numbers of *P. interpunctella* were caught outside the facility and at ground floor locations near outside openings. Additional traps placed in the rooms above the concrete stored-wheat silos at mill 1 during the second year captured more moths than did traps within the mill's production and warehouse areas. In another study, moths were trapped at various distances from a smaller flour mill (mill 2) to determine the distribution of moths outdoors relative to the mill. There was a negative correlation between moth capture and distance from the facility, which suggested that moth activity was concentrated at or near the flour mill. The effectiveness of the methyl bromide fumigations in suppressing moth populations could not be assessed with certainty because moths captured after fumigation may have immigrated from outside through opened loading bay warehouse doors. This study documents high levels of *P. interpunctella* outdoors relative to those recorded inside a food processing facility. Potential for immigration of *P. interpunctella* into flour mills and other stored product facilities from other sources may be greater than previously recognized. Moth entry into a food processing facility after fumigation is a problem that should be addressed by pest managers.

KEY WORDS Indian meal moth, stored-products, fumigation, methyl bromide

THE INDIAN MEAL moth, *Plodia interpunctella* (Hübner), is a serious and widespread pest of many stored food commodities (Hinton 1943, Sedlacek et al. 1996). Female *P. interpunctella* and females of other stored-product moths of the subfamily Phycitinae produce *Z*-9, *E*-12-tetradecandienyl acetate as a component of their sex pheromone blends (Brady and Nordlund 1971; Brady et al. 1971; Kuwahara et al. 1971a, 1971b). Traps baited with synthetic pheromone are effective and widely used to monitor male stored-product moths (Vick et al. 1981, Chambers 1990). Pheromone-baited traps have proven successful in detecting low level infestations of these moths (Vick et al. 1981).

Although many studies have focused on capturing phycitine moths inside storage and food processing structures (reviewed in Plarre 1998), only a few studies have documented outdoor activity of *P. interpunctella.* Ganyard (1971) used traps baited with virgin females as natural pheromone sources and captured less than one male moth per trap per day at outdoor locations up to 1.2 km from grain storages. A limited trapping study by Vick et al. (1981) with synthetic pheromone found *P. interpunctella* and the almond moth, *Cadra cautella* (Walker), inside a food warehouse, but no moths were trapped outdoors on the loading dock. Cogburn and Vick (1981) trapped *C. cautella* at rates of 18.8 and 23.8 moths per trap per week both inside and immediately outside rice storage bins, respectively, but recorded only 0.1–0.4 moths per trap per week at field sites 10–40 km away. Vick et al. (1987) placed pheromone traps for four species of storage moth pests in five outdoor locations along a 56-km transect from a peanut warehouse and only trapped substantial numbers of *P. interpunctella* in the area immediately outside the structure. These studies suggest that outdoor occurrences of moths such as *P. interpunctella* and *C. cautella* can be attributed to emigration from nearby storages, and that these species do not breed in outdoor habitats. Some researchers have concluded that moth infestations inside food processing facilities are mainly attributed to the introduction and storage of infested product (Levinson and Buchelos 1979) rather than to immigration of adults from outdoor locations.

In the current study we monitored *P. interpunctella* in and around two flour mills in 1997 and 1998. Specific

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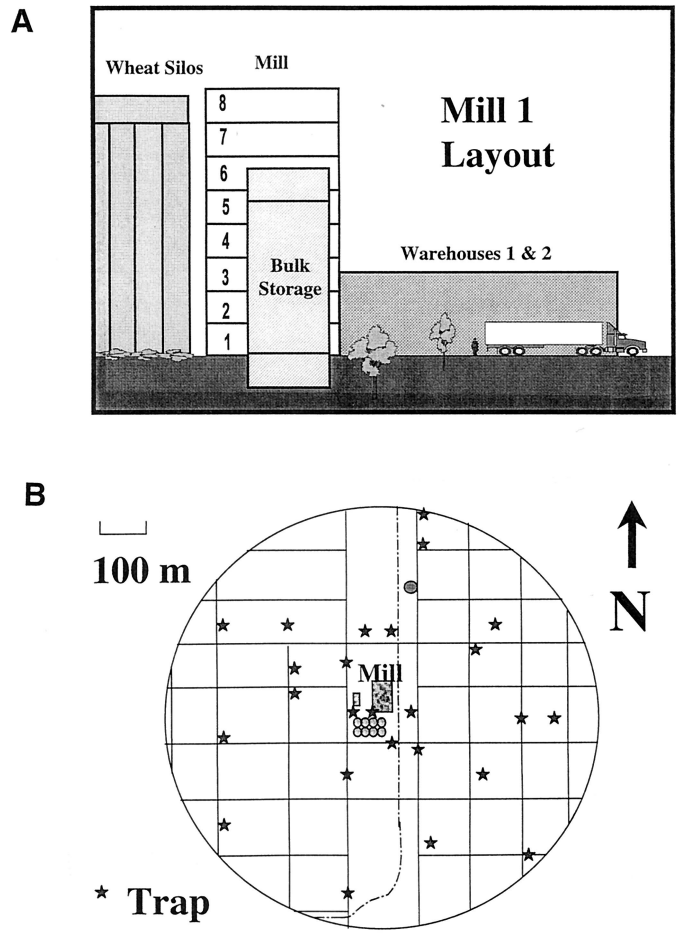

Fig. 1. (A) Facility components for mill 1, side view. Warehouse 1 was located directly behind warehouse 2 in this view. (B) Placement of moth traps around mill 2 for the spatial occurrence study. Stars represent traps, lines represent residential streets, the dotted line represents train tracks, and the single circle ≈200 m north of the mill represents a separate stored wheat bin.

objectives of the study were to document variation in moth activity at different locations and times both inside and outside the building, to determine *P. interpunctella* activity before and after methyl bromide fumigations, and to evaluate the outdoor occurrence of the moths at various distances from a mill.

Materials and Methods

Traps and Lures. Two types of sticky traps designed for flying insects, manufactured by Trécé (Salinas, CA), were used in these studies. The Pherocon III D, a delta-shaped sticky trap with constricted openings for moth entry, was used inside and immediately outside the flour mill in most experiments. The design of the Pherocon III D trap was ideal for this study because the small openings for insect entry also reduced fouling of the trap by the high levels of dust in the flour mill environments. The Pherocon II trap, a diamond-shaped sticky trap with larger openings than the Pherocon III D, was used to study outdoor moth activity in one experiment. Traps in all experiments were baited with pheromone lures provided by the manufacturer. Lures consisted of a rubber septum that released a single pheromone component, Z-9, *E*-12-tetradecadienyl acetate, and were placed on the trap's bottom inner sticky surface. Lures were replaced every four wks. Traps were replaced when needed because their sticky surfaces became covered with moths or dust, or at 4-wk intervals.

Flour Mill Studies. Mill 1 was a large commercial wheat flour mill that typically operated 24 h a day, 7 d a week. Traps were deployed in four areas of mill 1 for studies conducted in 1997 and 1998: the bulk grain storage area (comprised of concrete silos and elevators), an eight-story building housing milling and packaging operations, a bulk flour storage area, and two finished product warehouse areas (Fig. 1A). Indoor traps were hung from pipes or conduits two m above the floor, and were spaced from three to 10 m apart, depending on the size of the area monitored, in a line approximately centered along the room's long

dimension. During the 1997 study (1 May–26 November), traps were checked biweekly and all *P. interpunctella* counted. In 1997, two traps were placed on floors 3 through 8 of the mill area, two each in the rooms above and below the bulk-stored flour bins, two in warehouse 1 and four in warehouse 2. On 29 August 1997, two traps were placed 30 m apart outdoors in a field 50 m south of the mill and two other traps were put outdoors directly adjacent to the south side of the building, one trap near the rail car mill entrance and another on the south loading dock. Outdoor traps at mill 1 were positioned 2 m above the ground and were hung from tree branches or building hardware.

Mill 1 was also used for the 1998 study (16 June–5 November) in which traps were checked weekly and similarly deployed. No traps were placed on floors 4 through 8 or in the rooms above the bulk stored flour because of low moth capture in those areas in 1997. Traps were placed outside the mill at the beginning of the 1998 study: one in a field 50 m south of the mill, another 50 m north of the mill, a third 2 m south of the mill on the south loading dock, and a fourth trap attached to the outside wall of the mill on the west loading dock. An additional trap was placed in each of the three gallery areas above the wheat silos on 10 September.

Fumigations were conducted at mill 1 on 31 May 1997, 30 August 1997, and 4 July 1998 by a contracted fumigator. All areas of the mill were fumigated with the exception of warehouse 2 and the stored wheat silos. Flour inside the bulk storage bins was fumigated with magnesium phosphide, whereas the eight-story milling building, warehouse 1, and adjacent areas were treated with methyl bromide. All traps were removed 1–3 d before fumigations and replaced as soon after treatment as possible.

Outdoor Trapping Study. The outdoor area surrounding mill 2 was used in 1998 for a study of moth capture in pheromone traps relative to the distance from a mill. Mill 2 was in a different city from mill 1 and was about one-half the size and production capacity of mill 1. We selected mill 2 because it was located in a neighborhood that had few other obvious sources of Indian meal moths relative to the neighborhood of mill 1, which was located close to several commercial grain storage facilities. Twenty-eight traps were positioned throughout the residential area surrounding mill 1 at distances from 6 to 440 m in various directions (Fig. 1B). Traps with lures were attached ≈3 m high on utility poles on 24 September, collected after 1 wk on 1 October, and the number of *P. interpunctella* counted. The distance of each trap from the mill was determined using a survey laser instrument (model Criterion 400, Laser, Technology, Englewood, CO), sited from the trap location to the top of the mill's grain elevator. The geographic position of each trap relative to the mill was recorded by designating one of four directional quadrants (northeast, northwest, southeast, and southwest). All but the southwest quadrant contained seven traps; data from only four traps were recorded in the southwest quadrant because three traps were lost.

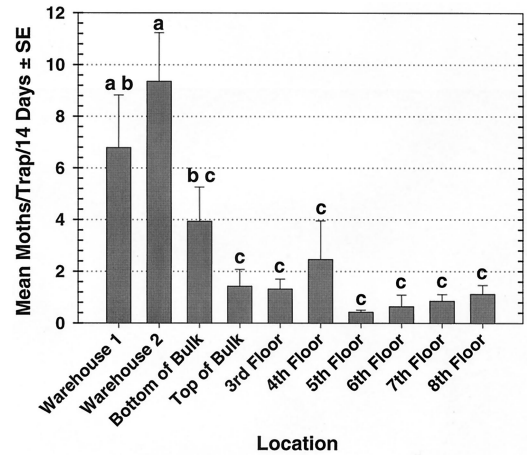

Fig. 2. Capture of *P. interpunctella* by location in mill 1 during 1997. Each mean represents 13 biweekly observations with four traps in warehouse 2 and two traps in all other locations. Means with the same letter are not significantly different (LS MEANS comparison).

Data Analyses. Moths caught per trap per trapping period at each designated location at mill 1 were plotted on a biweekly (1997) or weekly (1998) basis. Analysis of variance was performed in SAS using PROC MIXED followed by a means separation (LSMEANS) to test for differences in capture by location (SAS Institute 1996). Seasonal moth activity during the 1997 and 1998 studies at mill 1 was plotted by mean number trapped per day using the sum of moths caught at all locations during each trapping period. Moth captures from the outdoor study at mill 2 were analyzed by linear regression of square root transformed moth capture against distance in meters from the facility using PROC REG (SAS Institute 1996). Trap captures were analyzed for differences among quadrant directions and between north and south of the mill using PROC GLM; comparisons by direction were adjusted by using distance as a covariate (SAS Institute 1996).

Results

Capture of *P. interpunctella* in different locations at mill 1 during 1997 was significantly different by location ($F = 5.28$; df = 10, 15; $P = 0.0021$), with the highest captures occurring in warehouses 1 and 2 and the room at the bottom of the bulk flour storage (Fig. 2). Locations with the highest moth activity were all situated on the ground floor close to large outside openings. In 1998 the highest numbers of moths were recorded from traps in warehouse 2 (Fig. 3), but statistical analysis found no significant differences among the four locations studied ($F = 3.54$; df = 3, 4; $P = 0.1269$).

Moth activity in 1997 gradually increased during the season to a peak on 29 August, followed by decline to the end of the study (Fig. 4A). Moths were captured after each fumigation in 1997, and the moth population

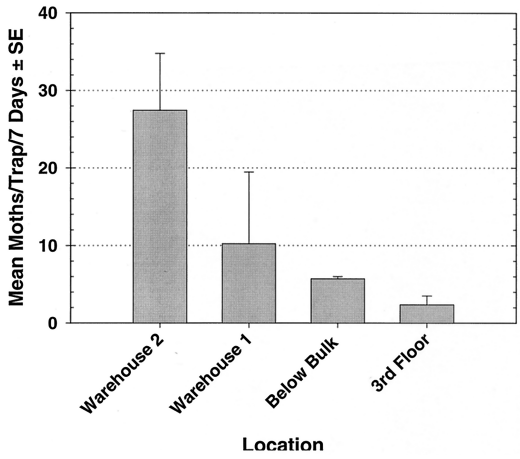

Fig. 3. Capture of *P. interpunctella* by location in mill 1 during 1998. Each mean represents 18 weekly observations with two traps in each area.

was clearly not eliminated as a result of these treatments. The seasonal pattern of moth capture in 1998 was similar to that in 1997, and moths were still captured after the 4 July fumigation (Fig. 4B). Traps outside mill 1 during 1997 captured more moths than did traps inside the mill (Fig. 5A). We observed a 36-fold higher capture of moths on outside traps compared with inside traps during the first comparison period that ended 16 September. Moth activity steadily declined in subsequent weeks both inside and outside the facility. Responses of moths to traps outside mill 1 or in the gallery of the grain silos were much higher in most cases than responses to traps inside (Fig. 5B). Significantly more moths were caught outdoors compared with indoors from 24 June through 10 September (PROC MIXED, $P < 0.05$ for all pairwise comparisons at each date), and captures in the gallery rooms of the grain silos were similar to or greater than those outside from 24 September through 5 November (Fig. 5B).

The numbers of *P. interpunctella* trapped at various distances from mill 2 ranged from two moths at 202 m to 120 moths at 6 m during a 1-wk trapping period (Fig. 6). Regression analysis revealed a significant negative relationship ($b = -0.0076$, $r^2 = 0.1883$, $P = 0.0302$) of moth capture with distance from the mill. After this study was completed an isolated bin of stored wheat, 200 m north of mill 2, was discovered (Fig. 1B). This bin could have served as a source of moths north of mill 2. A comparison of mean number of moths per trap north (43.2 ± 8.4 SE) versus south (17.8 ± 4.0 SE) of the mill was nearly significantly different ($F = 3.90$, df = 1, $P = 0.0623$). Differences in moth capture among the four quadrants around the mill were not significant ($F = 2.24$, df = 3, $P = 0.1145$).

Discussion

Three observations can be drawn from the studies reported above. First, *P. interpunctella* can be captured regularly in high numbers outside flour mills during the summer and early fall months, and occur in higher numbers close to the mill compared with far from the mill. Second, some of the *P. interpunctella* trapped inside mill 1 may have come from outside the building via the open doorways on the ground floor. Lastly, the wheat storage silos of mill 1 may have been a predominant source of moths captured both inside and outside the mill buildings.

An a priori assumption of this research was that *P. interpunctella* populations perpetuate inside the mill facility as a closed system. There was no expectation that moth activity outside the facility would be important to the spatial or population dynamics of moths in the mill. Thus, we initially deployed traps only inside the main building that housed the milling equipment and warehouses. However, substantial moth activity was observed inside the mill immediately after fumigations, and moth captures were consistently higher in areas of the mill near large outside openings. Additional traps were subsequently placed outside the mill in late August 1997. The resulting high moth capture outside led us to suspect that some moths trapped inside the mill may have immigrated into the

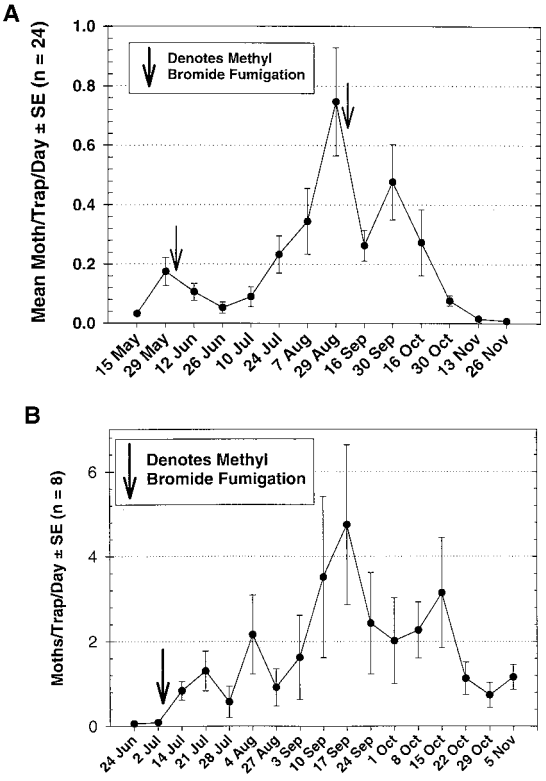

Fig. 4. (A) Daily indoor capture of *P. interpunctella* at biweekly intervals for all locations combined in 1997 at mill 1. Means represent 24 traps. Arrows denote methyl bromide fumigations on 31 May and 30 August. (B) Daily indoor capture of *P. interpunctella* at weekly intervals in 1998 at mill 1. Means represent observations from eight traps. Arrow denotes methyl bromide fumigation on 4 July.

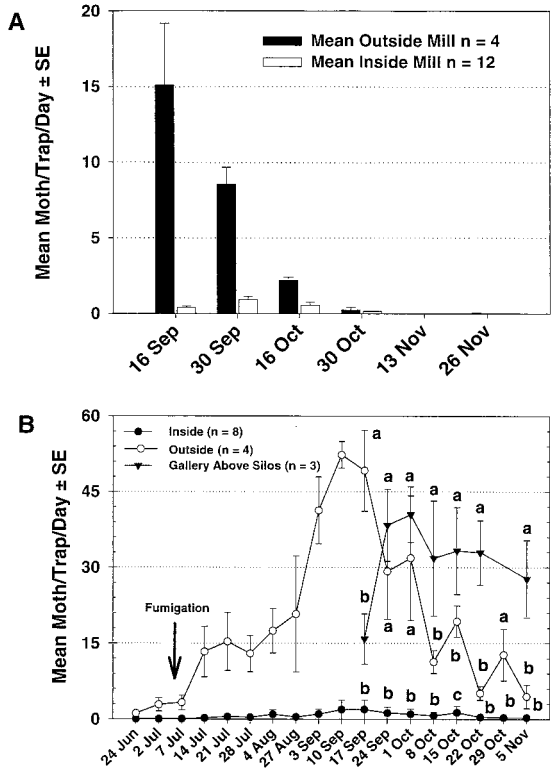

Fig. 5. (A) Numbers of *P. interpunctella* captured in pheromone traps outside and inside on ground floors at mill 1 during 1997. (B) Numbers of *P. interpunctella* captured in pheromone traps outside the mill, inside the mill and in the gallery rooms above the bulk-stored wheat silos at mill 1 in 1998. Means with the same letters are significantly different for a given date. Differences between inside and outside traps were significant at each date before 17 September.

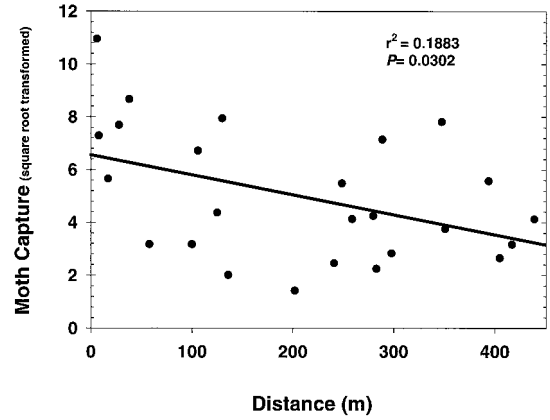

Fig. 6. Numbers of *P. interpunctella* captured in 1 wk at various distances from mill 2. Data points are the square root-transformed number of moths caught in 25 traps positioned 6–440 m from the mill.

building from outside via large doors that were frequently left open. Based on these observations, moth activity in the mill immediately after methyl bromide fumigation may reflect the immigration of moths from outdoors rather than low effectiveness of the fumigant.

Failure to suppress moth populations in a flour mill after fumigation has been noted in the past. Populations of *P. interpunctella* and *C. cautella* in a flour mill in Greece were only slightly reduced following phosphine fumigation, but those of *Sitotroga cerealella* (Olivier) and *Ephestia kuehniella* Zeller were reduced to below economically damaging levels (Levinson and Buchelos 1979). It is possible that *P. interpuctella* and *C. cautella*, which are ecologically similar species (Hinton 1943), are more inclined to fly outdoors than other storage moths, and readily reinvade structures after fumigation. Alternatively, capture of adult moths soon after structural fumigaiton may result from emergence of new adults from pupae that survived the fumigation (Levinson and Buchelos 1979).

In the current study, more moths were captured in the indoor gallery rooms above the grain silos than inside the flour mill building. Furthermore, numbers of moths captured in the galleries were similar to those caught outdoors, and moths were active in the silo galleries longer in the season (into the period of cool weather) than those outdoors. Therefore, it seems likely that many of the moths captured outdoors originated in the grain silos that contained an abundant food supply. Moths dispersing from the grain silos could easily invade the warehouse and other indoor areas through openings. Further study is required to substantiate this hypothesis.

The study of outdoor spatial occurrence of *P. interpunctella* around mill 2 found a significant negative correlation of trap catch with distance from the mill, but the relatively low regression value suggests that sources of moths, in addition to the mill, existed. Homes in the area could have been sources of *P. interpunctella.* Additionally, the sampling radius contained another single wheat silo in the northeastern quadrant (Fig. 1B) and two commercial wheat storage facilities were located within a kilometer (northeast and southeast) of the study area. The wheat storage facilities north of the mill 2 may have accounted for the greater number of moths trapped in the north versus the south quadrants. *P. interpunctella* males can disperse up to 1.6 km in 24 h (Ganyard 1971), and moths captured in this study could have easily dispersed from any of the potential breeding sites within and outside the study area. Although this study may suggest that *P. inerpunctella* are concentrated near mill facilities, we cannot determine if the flour mills act as sources or sinks for moths without further study using marked individuals.

In summary, these studies document high levels of outdoor activity of *P. interpunctella,* particularly around flour mills, and indicate the potential for immigration into food processing facilities. Infestation of food plants by Indian meal moths could occur both by storage of contaminated products and by immigration of flying moths. The current study only addressed activity of male *P. interpunctella,* and research on spa-

tial distribution and movement of female moths is needed. Additionally, the source of moths inside and outside food processing buildings needs to be determined. If wild populations occur, possibly developing on suitable food material in nonagricultural habitats, they would only increase the potential for moth infestation via immigration. Regardless of the source of immigrating moths, *P. interpunctella* populations will be difficult to suppress with fumigation unless better measures are taken to prevent moth entry into mills. Methods of limiting moth immigration are the use and maintenance of screens on doors and windows as well as limiting the time that large loading bay doors are open.

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