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RECENT DEVELOPMENTS IN THE USE OF PHEROMONES TO MONITOR *PLODIA INTERPUNCTELLA* AND *EPHESTIA CAUTELLA*

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INTRODUCTION

Stored commodities are particularly susceptible to insect infestation, in part, because food is rarely limited in storage facilities, and temperature and climatic conditions tend to be ideal for insect development. Furthermore, the handling involved in milling, processing, and transporting greatly increases the possibility of introducing insect pests into the commodity. These factors plus the very stringent requirements for absence of insects in processed commodities make sensitive insect monitoring tools necessary. Numerous entomologists have suggested that traps baited with sex pheromones may be ideally suited to this use.

A sex pheromone of the almond moth, *Ephestia cautella* (Walker), and the Indian meal moth, *Plodia interpunctella* (Hübner), was identified as (*Z*,*E*)-9,12-tetradecadien-1-ol acetate (Z9,E12-14:Ac) by Kuwahara et al. (1971b) and Brady et al. (1971). This chemical has since been identified as a sex pheromone of 3 other important stored-product moths; the Mediterranean flour moth, Anagasta kuehniella (Zeller) (Kuwahara et al., 1971a); raisin moth, Cadra figulilella (Gregson) (Brady and Daley, 1972); and tobacco moth, E. elutella (Hübner) (Brady and Nordlund, 1971). The fact that Z9,E12-14:Ac attracts 5 of the most important moth species to traps greatly simplifies the use of pheromone-baited traps for insect detection. This report concerns the use of Z9,E12-14:Ac for monitoring the moth population in 2 warehouses, the discovery of a new sex pheromone component for the Indian meal moth, and some calculations concerning dispersal of the pheromone in warehouses.

WAREHOUSE MONITORING

Although the vast majority of papers reporting results of insect monitoring with sex pheromones have been concerned with field crop, orchard, or forest insects, a few papers have reported data on warehouse studies. For example, Vick et al. (1979) found that the pheromone of the Indian meal moth and the Angoumois grain moth, Sitotroga cerealella (Olivier), could be dispersed from the same trap. They also investigated the effects of different rates of release of the pheromone and different trap designs on insect catch. Reichmuth et al. (1976, 1978, 1980) investigated populations of E. elutella in warehouses containing traps baited with sex pheromone. Hoppe and Levinson (1979) monitored populations of E. elutella, E. cautella, and P. interpunctella in a chocolate factory. All these scientists emphasized the use of pheromone-baited traps in timing applications of insecticides and in subsequent monitoring of effectiveness.

The monitoring study reported here was conducted in both commercial peanut warehouses and in military food warehouses. The traps were baited with Z9,E12-14:Ac obtained from Farchan Division of Storey Chemical Co., Willoughby, OH. It was purified so as to contain less than 2% of the Z,Z-isomer by elution through a 1.5 x 50-cm glass column containing 20% $AgNo_3$ on 60/200 mesh silica gel (Hi-Flosil-Ag®). Overall purity was about 98% as determined by GLC analysis on a 1.8 m x 2 mm ID column packed with 5% Carbowax 20M® on 100/120 mesh Chromosorb®. Ten mg of pheromone was dispersed from 250-ml capacity polyethylene caps (size #3, BEEM® polyethylene embedding capsule C) hung midway between the top and bottom of a Pherocon 1C® trap. New pheromone bait was placed in the trap every 2 weeks.

In the peanut warehouse, 4 traps were placed ca. 0.6 to 1.0 m above the peanut surface and ca. equal distances apart. Traps were checked 2 or 3 times/week depending upon the number of moths captured. This test ran for 1 year, from October 1977 to September 1978. During this period, the only lepidopteran insects trapped were E. cautella and P. interpunctella; about 20X more of the former than the latter were present in each collection. Fig. 1 shows the numbers of insects caught/trap per week. Catch increased steadily for several months after harvest and then declined during the cold months of February and March. The warehouse was fumigated with aluminum phosphine in February, but population levels, as reflected by trap catch, had returned to a high level by the middle of April. After the warehouse was emptied in June, the population declined, but insects were trapped at a fairly constant rate throughout the summer.

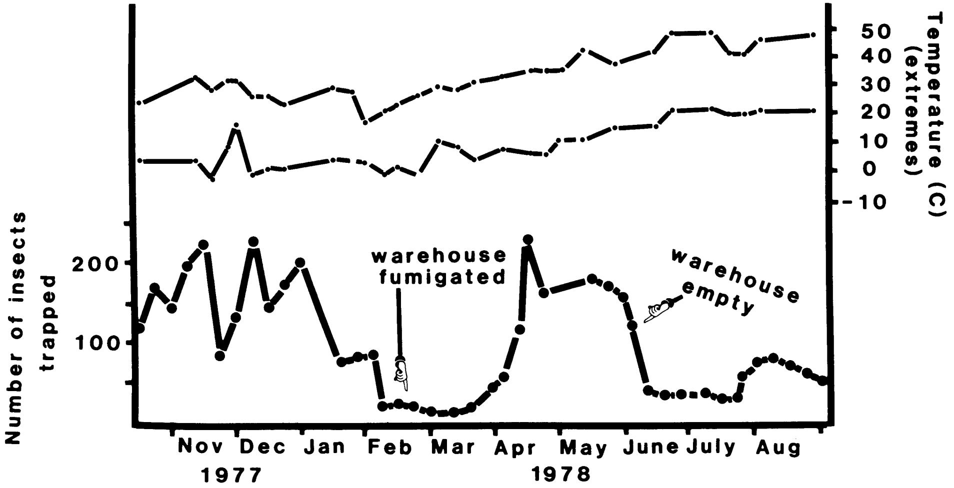

Fig. 1 Monthly pheromone trap catches of E. cautella in a peanut warehouse.

The results therefore showed the need for better insect monitoring tools for use in warehouses. Even in situations such as this where high insect populations can be tolerated, some gauge is needed to determine when a population has reached the economic threshold. For instance, in the peanut warehouse, the fumigant was applied inappropriately at a time when the population of adults was declining. Consequently, the fumigation was at best only partially successful.

The military food warehouse contained mostly processed, packaged food and was a modern facility that had been designed as a warehouse and had good lighting, wide aisles, etc. The warehouseperson in charge professed to know of no insect populations in the building. Six traps were placed in the warehouse, and one was placed outside on the loading dock. Traps in the warehouse were positioned near commodities that were more likely to be infested; i.e., dry cereals, dog food, cake mix, spaghetti, and flour, and were checked twice/week. Fig. 2 shows the weekly catches on the 6 traps for 17 weeks of the test. (The trap on the loading dock caught only a few insects.) Again, only E. cautella and P. interpunctella were caught in the warehouse. Insect densities as measured by trap catch, were not uniform throughout the warehouses. Some traps seemed to be situated in particularly infested areas. For instance, trap 5 caught more insects than any of the other traps in 13 of the 17 weeks. Trap catches were particularly heavy in traps 5 and 6 for weeks 14 and 15. Catches in traps 1 and 4 were consistently low, particularly during weeks when others were catching many more.

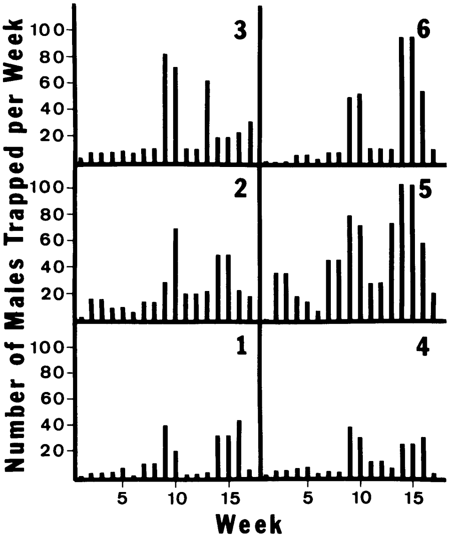

Fig. 2 Weekly pheromone trap catches of E. cautella and P. interpunctella at 6 different positions in a food storage warehouse.

This food warehouse like others, presented a difficult problem. Insect population levels must always be kept as low as possible; and detection of hidden infestations is especially important when the food is to be distributed over large geographical areas. Nevertheless, survey traps clearly showed an insect problem that had gone undetected. Additionally, the pheromone-baited traps seemed to pinpoint areas of high insect infestation. Knowing even the approximate locations of such areas is of great help in applying control measures.

IMPROVED PHEROMONE FOR P. INTERPUNCTELLA

A 2nd compound, (*Z*,*E*)-9,12-tetradecadien-1-ol (Z9,E12-14:OH), that is produced and released by *P. interpunctella* females was identified by Sower et al. (1974), Sower and Fish (1975) and Coffelt et al. (1978). Sower et al. (1974) could not ascribe a conspecific function for this alcohol in their laboratory tests, but they felt that the compound might also contribute to the sexual communication of *P. interpunctella*. Therefore, we attempted to determine the efficacy of Z9,E12-14 as a trap bait relative to female-baited traps, to discover if the alcohol is attractive to male moths and to evaluate the binary mixture as a trap bait.

Two tests were conducted in fall 1979 in a building that contained several hundred pounds of cull figs, which harbored a population of *P. interpunctella*. In both cases, we used Pherocon 1C traps containing 3 virgin females in a 7- x 5- x 4-cm screen cage or similar traps containing the test compounds. The test compounds were volatilized from 1 cm^2 fiberglass-coated PVC window screen. Traps were rotated to a different position each day, and one complete rotation (4 days) constituted one replication.

Table 1. Numbers of male *P. interpunctella* captured in traps baited with females, Z9,E12-14:Ac, Z9,E12-14:OH, or Z9,E12-14:Ac + Z9,E12-14:OH.

Treatment	Dose	No. Males Captured[1]
Z9,E12-14:Ac	4 mg	107 a
Z9,E12-14:OH	6 mg	10 b
Z9,E12-14:Ac + Z9,E12-14:OH	4 mg + 6 mg	1417 c
3 Females	-	492 d

[1] Numbers followed by different letters are not significantly different as determined by Duncan's multiple range test.

In the 1st test, we compared male captures in traps baited with females, Z9,E12-14:Ac, Z9,E12-14:OH, or a 40:60 mixture of the acetate and alcohol (Table 1). The acetate-baited traps captured significantly more moths than did the alcohol-baited traps. Similarly, traps containing the binary mixture captured ca. 14X more than those baited with the acetate alone and 3X as many as did female-baited traps.

In the 2nd test, we examined the relationships between dosage applied (binary mixture) and male trap capture. Traps baited with 3 females were included as the standard. Pheromone used in these tests was dispensed from window screen evaporators that were loaded with 10, 1, or 0.1 mg of the 60:40 (alcohol:acetate) mixture. Trap captures were highly correlated (r^2 = 0.999) with applied dosage (Fig. 3).

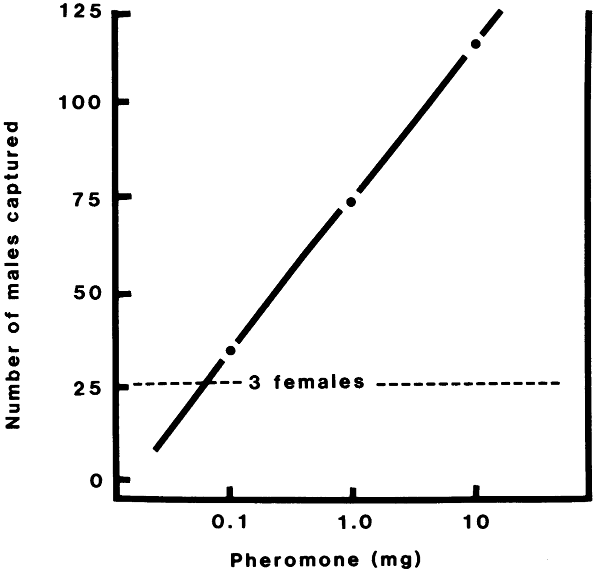

Fig. 3 Number of male P. interpunctella trapped in pheromone traps as a function of pheromone dose.

The results provided new information regarding the sex pheromone system of P. interpunctella and clearly showed that a mixture of Z9,E12-14:Ac and Z9,E12-14:OH was a more effective trap bait for this species than the acetate alone. The next step is to conduct detailed behavioral analyses and define the behavioral mechanisms involved in the sex pheromone response of male P. interpunctella. Studies already are in progress to establish the most effective release rates and substrates for these rather labile compounds.

PHEROMONE DISPERSAL IN A WAREHOUSE

In attempting to pinpoint sources of infestation, it is helpful to know the distance from which a trap attracts insects. Consequently, Mankin et al. (1980a) developed a model of pheromone dispersal in open and confined spaces that deals with the relationship among the major physical parameters of a warehouse environment. The pheromone concentration at some distance, r, from a source that has emitted pheromone for time, t, depends upon the emission rate, the positions of boundary surfaces, the pheromone diffusion coefficient, and the deposition velocity of pheromone to the boundary

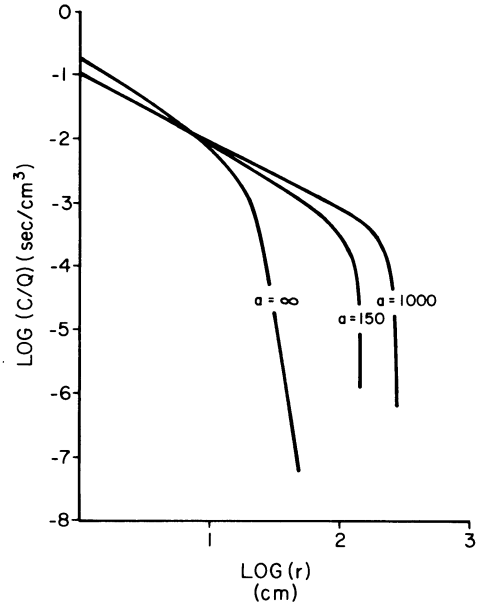

Fig. 4 Spatial distribution of the relative concentration of pheromone, C_r= Concentration/Release rate, at t = 60 sec after the start of release. The distance from pheromone source is designated by r, the position of boundary by a in units of cm.

surfaces. (The latter term is defined as the rate of deposition to a unit surface area/unit concentration.) Here we first consider some general aspects of these relationships and then present an example of how the model can be used to solve practical problems.

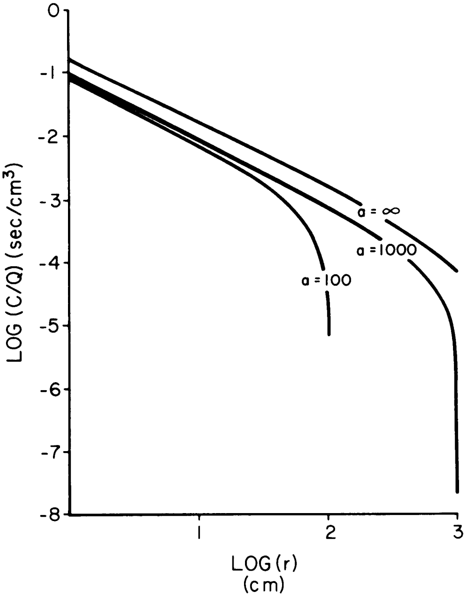

Fig. 5 Spatial distribution of the relative concentration of pheromone, C_r = Concentration/Release rate, at t = 2.5d after the start of release. The distance from pheromone source is designated by r, the position of boundary by a in units of cm.

Fig. 4 shows the effect of distance and boundary position on the ratio of pheromone concentration to its emission rate, C/Q, for the case where t = 60 sec, the diffusion coefficient, D, is 1 cm^2/sec, and the deposition velocity, V_d, is 1 cm/sec. The latter 2 values were chosen because they are fairly typical of warehouse conditions. Fig. 5 shows the identical case except that t has been extended to a duration more typical of a trapping situation, 8.6 x 10^5 sec. It is assumed that there is only one boundary surface, a sphere of radius a. Note that the smaller the boundary radius, the smaller the change in C/Q as the duration of emission increases. For example, the curve for a = ∞ changes considerably as the duration increases from 60 sec to 8.6 x 10^5 sec, but the curve for a = 150 cm at 60 sec differs little from the curve for a = 100 cm at 8.6 x 10^5 sec. Also, the difference between the magnitudes of C/Q in bounded and unbounded spaces decreases as the emission duration increases. Indeed, so long as r/a <0.9, the effect of the boundary is negligible at t = 8.6 x 10^5 sec, so we can assume that after long emission, the effect of a boundary on the pheromone concentration is negligible except at points very near the boundary.

To demonstrate a practical application of the model, we determined the active space of a trap used to capture male P. interpunctella in a warehouse and compared this with the active space of the pheromone-producing female. Previous studies indicate that the behavioral threshold of the male for its sex pheromone, Z9,E12-14:Ac, is about 1 x 10^{-8} ng/cm^3 (Mankin et al., 1980b). Typical pheromone traps for these insects emit 0.01 - 0.76 ng/sec (Vick et al., 1979). Over this range of emission rates, essentially the entire volume inside a boundary of either 100 or 1000 cm radius is an active space according to Fig. 5. The ratios 1 x 10^{-8}/0.01 = 1 x 10^{-6} and 1 x 10^{-8}/0.76 = 1.3 x 10^{-8} intersect the 2 curves for a = 100 and a = 1000 very near the respective boundaries. By contrast, a female Plodia, which emits about 8 x 10^{-4} ng/sec (Sower and Fish, 1975), has an active space of about 250 cm radius in a sphere of 1000 cm radius after it has called for 60 sec (see Fig. 4). In a sphere of 150 cm radius the active space covers the entire volume, but in an unbounded environment the active space has a radius of about 40 cm.

The model does have some defects, and should therefore be used with caution. For example, the traps in the food warehouse baited with 10 mg Z9,E12-14:Ac, emitting 0.76 ng/sec (Vick et al., 1979), theoretically have an active space greater than 10 m in radius. From this, one would not expect to find the large differences among the trap catches in Fig. 2. The effects of trap competition or habituation to the pheromone may have been a factor here.

Nevertheless, the model can be applied in a general way to predict optimal spacing and release rates for traps in closed environments, and the 2 insect surveys herein serve as an additional guide in planning future warehouse monitoring programs. We are optimistic that new developments, such as the improved pheromone blend for P. interpunctella, will increase the efficacy and the use of pheromone traps as monitors of insect pests in warehouses.

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