STORED-PRODUCT INSECT BEHAVIOR AND PHEROMONE STUDIES: KEYS TO SUCCESSFUL MONITORING AND TRAPPING

by

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Introduction

Behavioral studies have played an important role in the development of insect pheromones. It has been important to consider factors such as crowding, photoperiod, age, mating status, and feeding and reproductive patterns. In our studies with *Trogoderma* species and other beetles, crowding played an important role in the production and release of pheromone. Several species of *Trogoderma* will not release the most active pheromone component when crowded because the "calling" or abdominal tipping is inhibited (Hammack *et al.* 1976; Cross *et al.* 1976). In *Trogoderma*, photoperiod and age have been shown to have a dramatic effect on pheromone production and also on response to pheromones (Shapas and Burkholder, 1978a). Mating status generally affects pheromone production in those species that utilize female-produced sex pheromones.

In contrast, the maize weevil, in which the pheromone is male-produced and promotes aggregation, mating did not reduce pheromone release by males (Walgenbach *et al.* 1983). The response by virgin females to the pheromone was significantly higher than response by mated females, but males of either mating status responded equally well (Walgenbach *et al.* 1983).

Behavioral studies have not been restricted to adults. We have studied the influence of the molting cycle on the aggregation response of *Trogoderma glabrum* larvae to wheat germ oil (Nara and Burkholder, 1983). The larvae responded to the food attractant during a relatively short period of time during the intermolt period. The response was highest immediately after a completed molt and reached a minimum just before the next molt.

Two general types of communication and reproductive strategies of stored product beetles have been reported (Burkholder, 1982). Adults are either short-lived (< 1 month) and require no feeding for reproduction; or are long-lived (> 1 month) and need to feed for reproduction. The short-lived adults such as the moths, dermestids, bruchids and anobiid beetles rely on sex pheromones for communication. These sex pheromones are usually produced by the female. The long-lived adults such as the grain weevils, grain borers, the flour and grain beetles rely on male-produced aggregation pheromones for long-distance communication. Both males and females respond to the aggregation pheromones.

While the primary function of the sex pheromones is to promote mating, the function of the aggregation pheromones is probably more complex. Grain weevils survive for less than a week without food and water, so the importance of signaling the presence of both food and mates is obvious. Aggregations of 3 or more weevils are commonly observed at a single grain kernel, and the pheromone appears to play a role in their initiation. Since the task of chewing through the seed coat of a grain kernel requires a great deal of energy, the food sources may not be available without the efforts of several weevils.

The result of many of these behavioral studies has been the successful isolation, identification and synthesis of pheromones (Burkholder, 1981) or food attractants. Before a successful pheromone and attractant-based monitoring program can be initiated, it is necessary to have at least most of the appropriate lures and traps available. During the past several years we have attained this critical step. We now have available the primary lures for many Trogoderma species, the carpet beetles, the bean weevils, drugstore and cigarette beetles, the Tribolium flour beetles, the lesser grain borer, the larger grain borer, the rusty and flat grain beetles, the sawtoothed and merchant grain beetles, the maize weevil, rice weevil and granary weevil, plus most of the important moth species.

In our studies with the male-produced aggregation pheromones of Tribolium spp., the lesser grain borer and the Sitophilus spp. grain weevils we have learned that if the concentration of pheromone is too high the insects are not attracted but rather appear to be repelled by the pheromone. Using the Sitophilus weevils as an example, it appears that at low population levels the males and females both move around in the grain mass and the males, while feeding, release a pheromone that attracts other males and females. Male weevils do not produce pheromone when they are deprived of food. Therefore movement of insects in the grain may be a result of insects searching for good feeding sites or, for males or theoretically they may be moving away from high pheromone concentration levels. This is in addition to any movement related to temperature and humidity gradients or disturbance.

Lesser grain borer populations form aggregations in grain. I suggest that the newly emerged insects will migrate away from the established aggregations. Under crowded conditions the aggregation pheromone may therefore perform a dual purpose in signaling crowded conditions as well as being an attractant. It is apparent that in the grain mass insects are often migrating and may be effectively trapped by either unbaited or baited traps that are inserted in the grain. Trapping of these grain insects in the headspace of the bin or outside the bin does not seem to be nearly as difficult as in grain. In an open air situation the air currents prevent the buildup of high pheromone concentrations, however this could occur in grain.

The early field development phase of this work, especially with beetles, has emphasized the evaluation of trap designs that include pheromones and food attractants. Two of these studies involved the development of a corrugated paper insect trap and a plastic grain-probe trap. Additional recent information on stored product insect pheromones and traps has been reported by Burkholder (1984).

Corrugated Paper Insect Traps

The use of multilayered corrugated paper with pheromones for trapping stored-product insects was reported by Burkholder (1976), Barak and Burkholder (1976, 1984) and Williams *et al.* (1981). The corrugations are attractive to the insects as hiding sites similar to cracks in walls or floors. This behavioral response has been the key influence in the development of this trap. In our early studies we routinely used an insecticide in the traps to kill the insects. The corrugated paper was treated with either a residual insecticide or a volatile insecticide (Vapona). In response to concerns relating to pesticide use in food plants, we developed a modified corrugated trap that does not contain an insecticide (Barak and Burkholder, 1984) (Fig. 1). The trap contains a plastic dish holding approximately 30 drops (1 ml) of oil that both lures and kills the insects. Larvae and adults crawl or fall into the dish and die, apparently by suffocation. The oil lures consist primarily of wheat germ oil (Nara et al., 1981; Nara and Burkholder, 1983), oat oil (Freedman et al., 1982; Mikolajczak et al., 1983) and mineral oil. Several volatile components including octanoic acid have been identified from wheat germ oil. These volatiles initiate aggregating activity in *Trogoderma* larvae (Nara et al., 1981). Mikolajczak et al. (1984) have reported on a number of different compounds in oats that attract sawtoothed grain beetles. The most active compounds were (*E*)-2-nonenal and (*E,E*)-2-4-nonadienal. Other active compounds were hexanal, heptanal, octanal, (*E*)-2-heptenal, and 2-furaldehyde. Subsequent studies have resulted in further identifications of highly active attractants in oat oil. This trap is unusual in that the lure is also the killing agent.

The trap also accommodates pheromone-treated rubber septa. Up to four different pheromone-treated septa may be used at one time. Oil lures are especially effective for *Trogoderma* spp. larvae, adult sawtoothed grain beetles, *Oryzaephilus surinamensis*, and *Tribolium*. The combination of food and pheromone lures has greatly improved the usefulness of the trap. The traps with pheromones and attractants are available from the Zoecon® Corporation, P. O. Box 10975, Palo Alto, California 94303 under the STORGARD™ label.

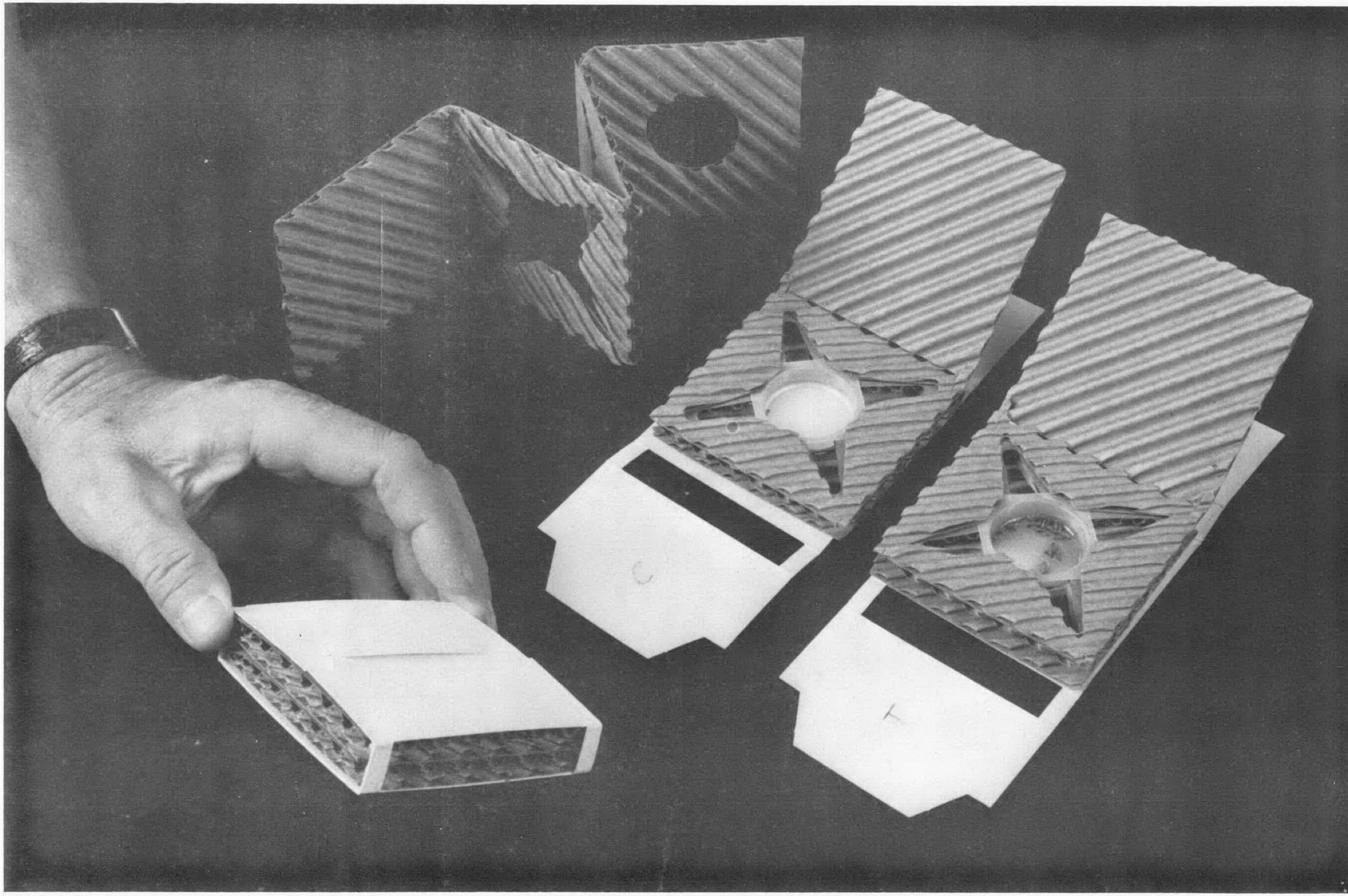

Fig. 1. View of corrugated paper trap (9 x 9 x 2 cm) with a plastic dish containing an absorbent paper pad and approximately 30 drops (1 ml) of an oil lure that also serves as a killing agent. Pheromone-treated rubber septa are placed in the V-notched sections of the trap.

Grain Probe Insect Traps

The use of perforated grain probe insect traps with pheromones is a relatively new procedure. A perforated brass trap was described and tested by Loschiavo and Atkinson (1967, 1973), Loschiavo (1974, 1975) and Barak and Harein (1982) which did not utilize pheromones or other lures. Major drawbacks of the metal trap have been its high cost and lack of commercial availability. During the past several years a new plastic grain probe trap has been designed and evaluated in our laboratory. The trap is inexpensive, can be easily mass-produced and has superior effectiveness with or without pheromones or food lures. Lures, if used, can be easily inserted. The plastic selected, Lexan®, is transparent, has extremely high impact resistance and strength, and can be easily machined. Another advantage of the 2.5 cm tube selected was that the 3.2 mm walls allowed the machining of sloping holes. The trap has 186 holes that are 2.79 mm in diameter that slope at a 50° angle (Fig. 2). The trap is also available with larger holes (3.79 mm) for large grains such as corn. The upper end of the trap is closed with a plastic plug that is perforated to allow the insertion of one or several 3.2 mm polyethylene tubes or nylon rods of various lengths. Rubber septa containing pheromones or food lures may be attached to the tubes or rods. The tubes may be used directly as attractant-releasing devices by sealing attractant compounds inside them. A rope attached to the top of the trap is useful in securing and recovering the trap.

Insects fall or crawl into the trap and drop through the plastic funnel into the lower part of the device. A clear plastic tube insert is provided to make removal of the insects easier. The tube is marked in a graduated scale (ml) in order to estimate by volume large numbers of the trapped insects. A thin film of white petrolatum (U.S.P.), mineral oil (food grade), or the oil lures used in the corrugated paper traps (1 ml), may be used inside the tube insert to kill the trapped insects. The oil lures are especially useful in luring a wide variety of insects, including larvae. Care should be taken to prevent the oil from getting on the insect entry holes. A quick-release lower plug allows easy access to the trapped insects. A metal device has been designed to fit over the trap to facilitate pushing it into the grain (Fig. 3). This device can be attached to the standard Seedburo T-handle and threaded extensions available for the deep-probe grain sampler. It is also useful as a tool to quickly remove the lower plug of the trap.

The aggregation pheromones of both the lesser grain borer and Tribolium have been used successfully with the trap. When compared to the control, 3-4 times as many insects were caught in the traps during field studies with Tribolium pheromone (R. Cogburn, unpublished) and the lesser grain borer pheromone (R. Cogburn, unpublished and R. Mills, personal communication). My studies have demonstrated the importance of pheromone concentration when grain-probe traps are used. By employing various concentrations of lesser grain borer

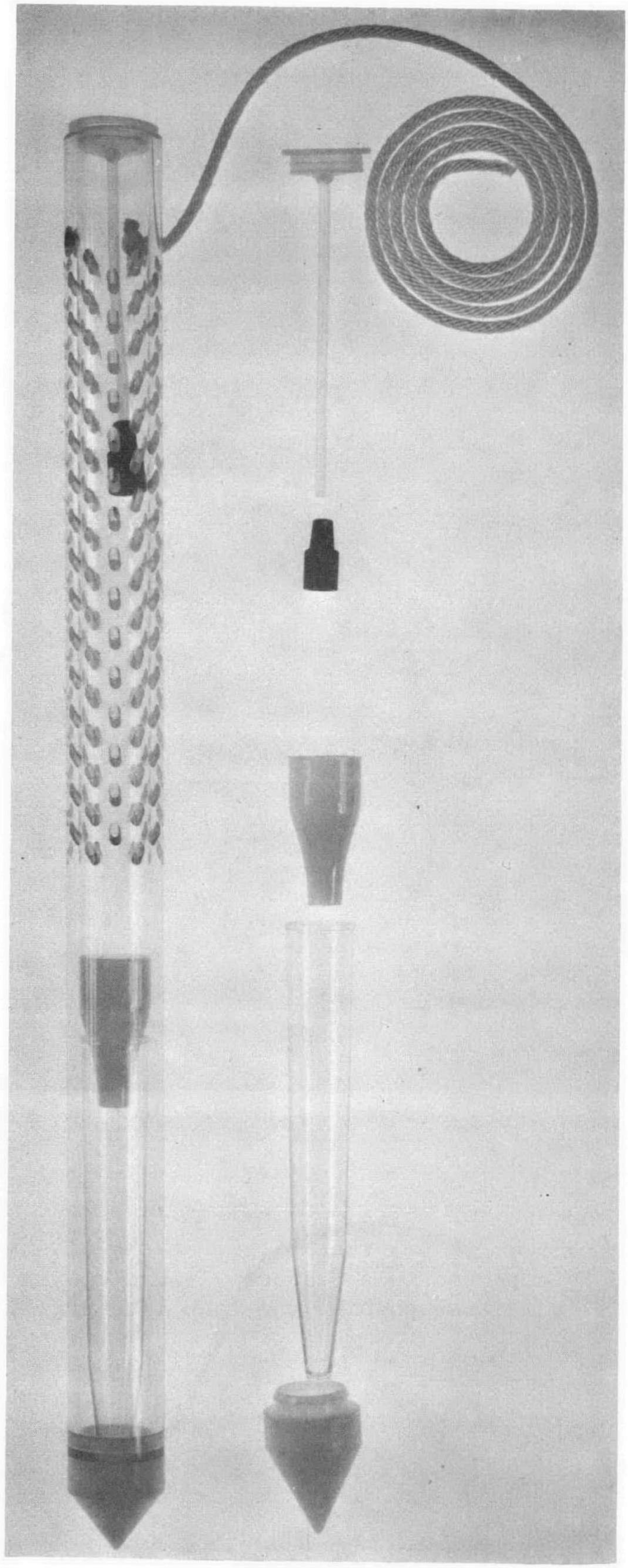

Fig. 2. View of plastic grain-probe insect trap, on left the assembled trap (2.5 x 38 cm); on the right the component parts (top to bottom) - plastic end cap with tube for dispersing attractants or for attachment of rubber septa; the rubber septa; plastic funnel; plastic graduated test tube; plastic snap-off cap.

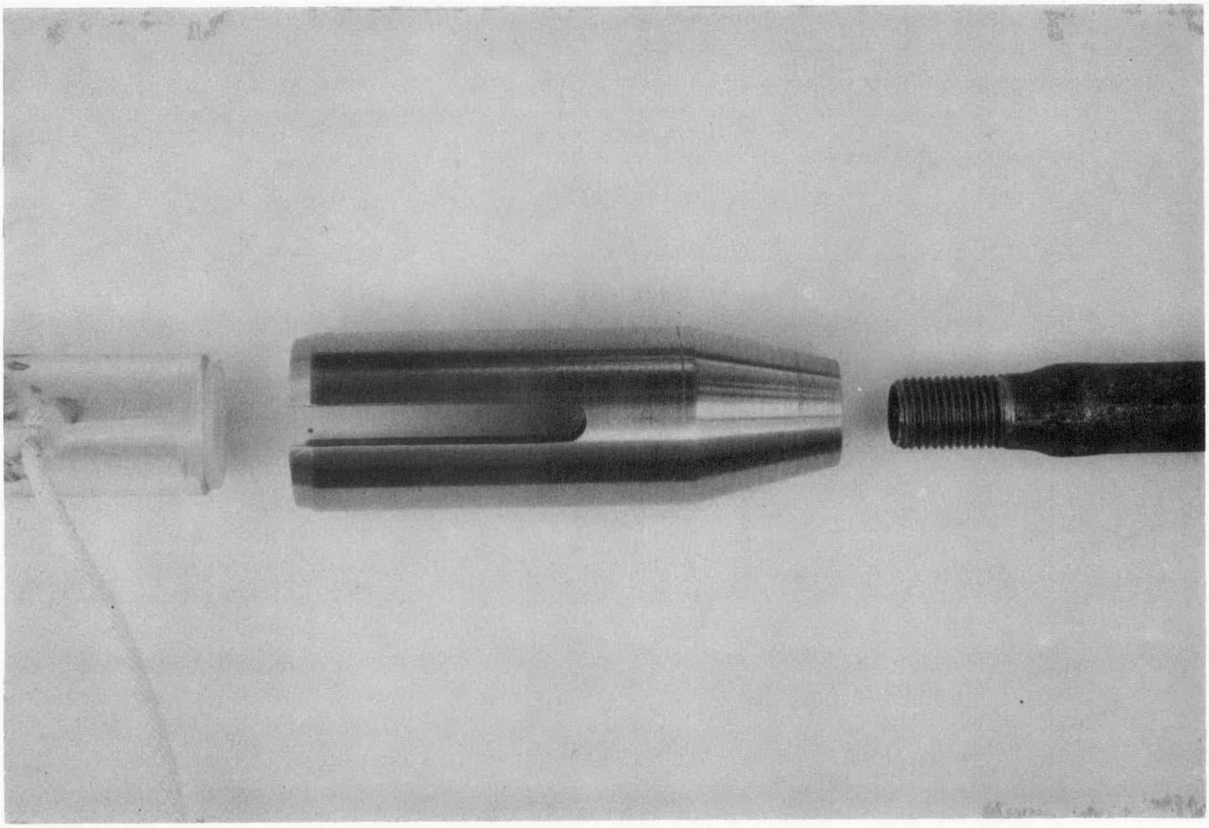

Fig. 3. View of metal device (9.5 x 3.1 cm) that fits over the plastic grain-probe trap and is attached to a Seedboro T-handle with threaded extension to facilitate pushing the trap into grain.

Trogoderma males in field studies. International Pheromones Limited is currently marketing a funnel trap for stored-product moths. Insects are killed by an insecticide inside the trap. While the insecticide restricts its use in food plants, this trap usually has a larger insect capacity than the adhesive kind.

The grain probe trap has been modified for use in head-space areas of bins, in warehouses and outdoor settings. Modifications include a rain or dust cover and a funnel with a 2.5 cm diameter hole in the narrow end. The funnel is slipped over the probe trap to direct insects into the holes. When a large reservoir is required the bottom end plug and tube insert is replaced with a .4 liter plastic bottle. Cogburn (personal communication) has found the probe trap,when attached to posts and trees, to be effective in catching lesser grain borers.

Trap Placement and Interpretation of Trap Catch

Placement of the corrugated paper traps in warehouses is dependent in part on the size of the warehouse and on available supporting posts or other places where there is little or no traffic. It is suggested that they be placed approximately 16 m apart in a general grid system so that all areas are evaluated. Our studies in California (Smith et al., 1983) with Trogoderma pheromone in cardboard traps demonstrated that in one warehouse greater trap catches occurred near exterior walls with doors. In another warehouse, the largest trap catch was inside and away from the walls, indicating an infestation or potential site of an infestation. There was no significant difference between traps placed 1.5 m above the floor or on the floor.

In general, the traps should be placed away from open doors or windows to avoid attracting insects into a facility from outside. Moth traps are usually more effective if placed at near ceiling levels (personal communication, Dr. Jim Sargent).

In trapping studies with the lesser grain borer pheromone (dominicalure) outside rice bins in Texas Cogburn et al. (1984) found that more lesser grain borers were caught in traps placed near the concrete supporting slab than at 2 or 6 m above the slab. In our studies (Williams et al. 1981) pheromone treated corrugated cardboard traps worked well when placed on storage room floors; pheromone treated adhesive traps were effective when suspended 2.4 m above the floor.

In Tanzania R. J. Hodges and colleagues have utilized the dominicalure pheromones to determine the presence of both lesser grain borers and Prostephanus truncatus, the larger grain borer, in farm maize stores (personal communication). Pheromone treated corrugated paper traps were placed either inside the farm storage house or outside on a storage platform. Dominicalure may therefore be used for pheromone I was able to demonstrate that high concentrations (30 mg) were significantly repellent to the insects when compared to the control or to lower concentrations (1, 3 or 10 mg). A similar effect occurs with the Tribolium pheromone. Experience in California rice storages has indicated that approximately 10 times as many Tribolium are caught in the plastic grain-probe traps after 3 to 4 days when compared to grain trier samples. Studies in progress will undoubtedly add to the information on time-temperature effects, type of grain, trap placement, pheromone concentration effects and other ecological information. In addition, our studies (Qi and Burkholder 1982; Kramer et al. 1984) have demonstrated the usefulness of probe traps in detecting insects in oil or repellent-treated grain.

A significant factor in the use of these grain-probe traps is that by leaving the traps in place for one to several days, a much greater sensitivity to grain infestation occurs. In this way, the traps will detect infestations when grain trier samples do not. Also insect migrations in grain are well known and the traps will detect such movements. These traps may be used continuously from the day the grain is stored until it is marketed. It is possible to push the traps into the grain and remove them from bin openings without direct contact with the grain. The traps are virtually indestructible but they should be removed when liquid fumigants are used.

The plastic grain-probe trap is manufactured by Walco Mfg. Co., 282 Jefferson St. Oregon, Wisconsin and is marketed by the Zoecon Corporation, Palo Alto, California under the STORGARD™ label. Pheromones and attractants for use in the traps are also available from them.

Adhesive Traps

Perhaps the most common method of trapping insects, especially moths, has been to apply adhesive material to an environmentally protected surface such as cardboard or plastic. Several companies supply such moth traps. Cogburn et al., (1984) utilized 2 inverted plastic pie plates separated by a 4.8 cm diameter PVC pipe. Adhesive was applied to the upper surface of the lower plate. The advantage of this trap is durability, low cost and ease in which it can be either hung inside or staked outdoors. The trap was successful in capturing both moths and beetles, especially the lesser grain borer and Sitotroga cerealella, the Angoumois grain moth. Commercial adhesive traps are routinely used for trapping Trogoderma spp. adults. Williams et al. (1981) used commercial adhesive traps for evaluating the lesser grain borer aggregation pheromone.

Funnel Traps

A variety of funnel traps has been used for trapping both stored product moths and beetles. Shapas and Burkholder (1978b) utilized a small funnel attached to a bottle baited with pheromone to trap adult simultaneous monitoring of the two species in areas such as Kenya and other East African countries where the larger grain borer is especially threatening to the maize crops.

Indian meal moths have been successfully trapped utilizing either rubber septa, hollow fibers, or plastic materials baited with pheromone. Vick et al. (1981) reported that traps baited with 4 mg (Z,E)-9,12-tetradecadien-1-ol acetate captured significantly more moths than traps baited with 6 mg of (Z,E)-9-12-tetradecadien-1-ol. Traps containing a mixture of the 2 compounds caught 14 times as many moths as did those baited with the acetate alone and 3 times as many as did traps baited with 3 females. Stockel and Sureau (1981) reported satisfactory results in trapping the Angoumois grain moth with pheromone amounts between 300 and 900 ug/rubber septa dispensers.

Traps, if protected, may be placed outside of warehouses to catch migrating insects and therefore intercept insects before they have a chance to move inside. Trapping should begin when temperatures reach approximately 19°C. May through October are usually the months of most intensive use except in heated areas or in semi-tropical or tropical areas where year-round trapping is necessary.

Pheromone lures should be protected from heat prior to their use and should be replaced according to the manufacturers' recommendations. Trapped insects should be removed promptly from the corrugated paper traps. It is important to keep an accurate map of trap locations in order to prevent leaving them unattended. The traps should be inspected at least once a week and the trap catch counted and recorded. Lures and traps should be disposed of promptly and according to manufacturers' directions.

The interpretation of the trap catch is not difficult. One or several insects in a trap usually indicates the presence of a small infestation or accidental entry of stray insects. Repeated catches over a period of several weeks indicates the likelihood of an infestation. Large numbers of insects (10-30) usually indicate a serious problem. If the traps are placed on a grid system the first week's catch may pick up stray insects in a random pattern. In subsequent weeks the trap catch will likely indicate more precisely the problem areas by pin-pointing active insect sites. Repeated trapping may offer partial control by eliminating some of the offending insects as well as impairing reproduction.

Discussion

Use of these traps has resulted in the detection of elusive insect infestations. Savings include reduced product loss and insecticide usage because of quick and efficient localized treatment. Follow-up trapping has been recommended to monitor continued elimination of insect infestations in these instances.

Pheromone traps can be expected to attract insects from a relatively large area and therefore should uncover insect activity sooner than conventional sampling methods. Plant managers, sanitarians, as well as commercial pest control personnel, have a new insect threshold level to consider. If the density of insects can be kept below tolerance levels by trapping, at least partial control may be achieved. Time is allowed for other environmentally sound insect control practices such as improved sanitation, aeration of grain and correcting construction faults.

Pheromone traps may be used to catch migrating insects. For example, studies by Williams and Floyd (1970) with maize weevils suggest that emigrating weevils may not fly directly to the corn in the field, but may fly to some other host, before the corn becomes susceptible. The male-produced aggregation pheromone of the maize weevil could be used to trap these insects before they have a chance to infest corn in the fields. In addition pheromone traps could be used to intercept insects before they migrate from the field or other sources to storage bins, warehouses or other storage facilities.

The many years of basic research in the area of stored product pheromones have resulted in some commercial applications. Recent advances in trap design along with success in developing broad-spectrum food lures for stored-product beetles has stimulated commercial development of new insect monitoring systems.

Summary

Synthetic pheromones and food attractants are giving the food industry highly effective new tools for early detection of insects. The introduction of new attractants and traps in recent months has resulted in an enthusiastic response by food plant managers as well as the pest control industry. Packages are now offered that include pheromones and attractants for trapping important storage pests such as *Tribolium*, *Trogoderma*, the lesser grain borers, sawtoothed grain beetles and several moth species. Pheromones for the grain weevils and other species will soon be available. The traps provide vital information about the identity, location and the population density of the pest species. The traps are more effective than conventional sampling procedures, they are working continuously over a period of time and therefore, as expected, are much more effective than the conventional sampling procedures. It may now be possible to control insects more easily because of the early and accurate information provided by the traps. If the density of insects can be kept far below tolerance levels by trapping, at least partial control is achieved. If improved sanitation, aeration and other similar control measures are provided the job is much easier.

Pheromone trapping also offers a savings in time spent on visual and manual searches. Pinpointing the source of an infestation allows spot treatments rather than treatment of an entire facility. A number of examples of this have been provided by the food industry. The trapping system has also been able to locate faults in construction that harbor residual insect infestations. Pheromones are powerful tools, and when handled properly, aid in the effective management of pest insects. Newly designed traps and the food and pheromone lures offer a bright future for detecting and monitoring stored product insects. Pesticide application costs should be reduced because of better timing of applications. The objective is to avoid unnecessary pesticide treatments. Advances in other areas such as improved aeration systems and biological controls will aid in this effort.

Acknowledgement

Research supported by the College of Agricultural and Life Sciences, University of Wisconsin, Madison, and by a cooperative agreement between the University of Wisconsin and ARS, USDA. I thank Alan Barak, Janet Klein, Catherine Walgenbach and Joel Phillips for reviewing the manuscript. The assistance and contributions of Dave Walford, Walco Mfg., Oregon, Wisconsin during the development of the plastic grain-probe insect trap is greatly appreciated. Mention of a proprietary product or company name in this paper does not constitute an endorsement by the USDA.

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