THE USE OF PHEROMONES IN STORED PRODUCTS PROTECTION: A UK VIEW

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ABSTRACT

The ability to detect pest insects is fundamental to most recent strategies of stored product insect control. Early warning of pest presence can be used to prevent damage and an efficient detection programme can lead to a reduction in losses and pesticide use. Enhancement of physical traps by use of attractant chemicals is a worthwhile objective and over the last decade many pheromones have been isolated and identified from stored product pests.

The value of TDA pheromone in both funnel and sticky traps to improve detection of moths of Ephestia spp has been clearly demonstrated in the flour milling and confectionery producing industries. However, the complexity and specificity of many of the stored-product beetle pheromones and the lack of evidence for long range effects has resulted in far fewer successes in the practical use and application of these pheromones.

There have been considerable advances in techniques for the physical trapping of insects in bulk cereals and although some pheromone components may offer improvements in trapping efficiency it may be that less specific food attractants may be used to produce more effective and practical traps.

INTRODUCTION

Detection of insect pests in raw and processed food stores is of fundamental importance to insect control programmes. There have been many proposals for techniques to supplement visual inspection, usually in the form of a trap with or without a supplementary chemical lure. However, there is frequently a very long time gap between the successful evaluation of a trap for monitoring the presence of insects and the adoption of a system in commercial practice. An interesting chemical which is very active in the laboratory may be totally inappropriate or ineffective in practical food storage programmes. In this paper we will attempt to discuss some of the reasons for this and present a personal view of the practical potential for pheromone traps in the UK.

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Detection

The value of efficient pest detection for the prevention of losses has been recognised by many authors including Solomon (1965), Howe (1966) and Levinson and Levinson (1978). Many of the early proposals were for sticky, crevice or pitfall traps and some of the designs were shown to be successful in practical use. Suspended sticky "fly paper" traps have been used for monitoring moths and other flying insects in warehouses and food processing plants in a number of countries. Crevice traps constructed of corrugated card or sacking have been described (Howe 1950) but do not appear to have been adopted on a large scale. Pitfall traps made from glass jars sunk level with the surface of bulk cereals have been used for a number of years in Germany. The probe trap devised by Loschiavo and Atkinson (1973) for monitoring pests in bulk cereals is a combination of a pitfall and a crevice trap. Although many stored-product entomologists were interested in this design and its reported success (Loschiavo, 1975), many years passed before a trap based on this design was launched commercially (Burkholder, 1984). The effectiveness of these probe traps will be discussed in more detail later in the paper. Enhancement of traps with food lures has been described by Levinson and Levinson (1979), Barrer (1983) and Pinniger *et al.*, (1984) describe the evaluation and successful commercial use of a bait bag containing foodstuffs. A corrugated cardboard trap which incorporates an oil-enhanced pitfall is marketed by Zoecon Ltd. Burkholder (1984) and Endacott (1985) describe the successful use of these Storgard™ traps.

However, it is studies of insect pheromones which have resulted in the widest range of proposals for trap enhancement with pheromone components or analogues. It may be significant that the stimulus for this interest in pheromones has usually come from University departments rather than from people in the trade with particular problems.

Pheromones may have very different functions in controlling insect behaviour and the most frequently used division is between "sex" pheromones which are produced by one sex and attract the other and "aggregation" pheromones which may be produced by one sex and attract both sexes. This classification may be inappropriate and the number of pheromone components present in some species eg *Oryzaephilus surinamensis* deserves a more detailed examination of function. Burkholder (1982) classifies pheromones and insect behaviour in terms of short-lived adults which need to find mates and reproduce within a short time period and long-lived adults which may not need to be so hasty and produce food exploitation pheromones which may also have a sexual function. It is also possible to group together those species where adults and larvae may occupy different environmental niches and have different food requirements in contrast to other species where adult and juvenile stages live alongside one another and consume the same foodstuff. Before discussing the value or relevance of these distinctions or classifications it is necessary to examine some examples of pests, pheromones and their potential.

Pests and Pheromones.

Table 1 lists some examples of stored-product pests, their pheromones and key papers. This list is by no means comprehensive but is intended to include the major pests with the emphasis on cereal storage and processing in temperate countries.

Phycitid moths

Phycitid moths have a number of different pheromone components but (Z,E)-9,12-tetradecadienyl acetate (TDA or ZETA) is common to all the major stored product moths found in the UK, namely Ephestia elutella, E.cautella, E.kuhniella and Plodia interpunctella. Traps containing TDA lures can be used for the detection of all these species and they became commercially available in the UK in 1978. Reichmuth et al., (1978) and Cogan (1983) describe trials with sticky traps and funnel traps in the laboratory and in commercial storage in Germany and the UK. Both trap types are currently used in the UK in flour mills, warehouses and food processing plants. Many companies have initiated an integrated trap inspection and control programmes and have determined specific trap catch thresholds for the implementation of cleaning, insecticide treatment or fumigation. The success of control programmes based on pheromone trap data has been shown by decrease in insect numbers and customer complaints together with more efficient and reduced use of contaminating pesticides. It is important to consider trap design in relation to practical use: Cogan and Hartley (1984) report that some funnel trap designs are more effective than sticky traps in dusty environments but may be less effective in other areas. It has also been shown by Haines (1976) and Hodges et al., (1984a) that release of relatively large quantities of TDA causes reduction in mating and population suppression of Ephestia species. This aspect of pheromone use may offer possibilities for control in the future but is outside the scope of this paper.

Anobiid beetles

Serricornin, the pheromone produced by female Lasioderma serricorne (Chuman et al., 1979) is now available in sticky trap lures for use in tobacco storage and processing. They have not been available in the UK for sufficient time for reports of their use in practice to be published.

Stegobinone, the pheromone of Stegobium paniceum has been described by Kuwahara et al., (1978) but there appears to be little published work on the evaluation of this compound and its effect in traps. We undertook a study on the synthesis of stegobinone from rhamnose and Cassidy (1985) reports that males are attracted to a pheromone source (Table II). It is probably that a stegobinone lure could be used in a trap to successfully detect S.paniceum and this conclusion has been supported by Kodama et al., (1986).

TABLE I Pheromone components of some of the major stored product pests.

Insect species	Pheromone Components	References
Cryptolestes ferrugineus	(Z)-3-dodecen-11-olide 4,8-dimethyl-(E,E)-4,8-decadienolide	Pierce et al., 1984
Lasioderma serricorne	4,6-dimethyl-7-hydroxy-nonan-3-one	Chuman et al., 1979
Oryzaephilus surinamensis	(Z,Z)-3,6-dodecadien-11-olide (Z,Z)-3,6-dodecadienolide (Z,Z)-5,8-tetradecadien-13-olide	Pierce et al., 1984
Prostephanus truncatus	1-methylethyl(E)-methyl-2-pentenoate	Hodges et al., 1984b
Rhyzopertha dominica	1-methylbutyl(E)-2-methyl-2-pentenoate 1-methylbutyl(E)-2-dimethyl-2-pentenoate	Williams et al., 1981
Sitophilus oryzae	4-methyl-5-hydroxy-3-heptanone	Schmuff et al., 1984
Stegobium paniceum	2,3-dihydro-2,3,5-trimethyl-6-(1-methyl-2-oxobutyl)-4H-pyran-4-one 2,3-dihydro-2,3,5-trimethyl-6-(1-methyl-2-hydroxybutyl)4H-pyran-4-one	Kuwahara et al., 1978 Kodama et al., 1986
Tribolium castaneum	4,8-dimethyldecanal	Suzuki 1980
Trogoderma granarium	(Z,E)-14-methyl-8-hexadecenal	Cross et al., 1976
Ephestia cautella Plodia interpunctella	Z,E)-9-12-tetradecadienyl acetate (Z)-9-tetradecen-1-yl acetate (Z,E)-9,12-tetradecadien 1-ol.	Kuwahara et al., 1971 Brady, 1973 Read and Beevor, 1976

TABLE II: Response of male Stegobium paniceum to stegobinone over a 10 minute test period.

	% Responders	% Non Responders	$\bar{x}$ time to reach target in seconds
Control	0	100	600
270 ng	50	50	370
540 ng	100	0	121

Dermestid beetles

The complex series of pheromones of *Anthrenus* spp, *Attagenus* spp and *Trogoderma* spp have been well documented by Barak and Burkholder (1976), Burkholder and Ma (1985) and others. Trogodermal lures have been used successfully in Storgard traps (Burkholder, 1984) but there have been no trials in England as *T.granarium* is not a UK pest. The importance of some *Anthrenus* spp as fabric pests could make a lure for *A.verbasci* potentially valuable.

Bostrychid beetles

The identification and evaluation of dominicalure, the aggregation pheromone of the lesser grain borer *Rhyzopertha dominica* has led to the production of commercial lures. The male produced pheromone attracts both male and female beetles (Cogburn *et al.*, 1984) and also males and females of the closely related larger grain borer - *Prostephanus truncatus* (Hodges *et al.*, 1983). The pheromones of *P.truncatus* have since been determined and evaluated in field trials by Hodges *et al.*, (1984b). The importance of the spread of this pest in Africa has led to a monitoring programme using Trunc-call traps. Fortunately for the UK grain trade, *P.truncatus* has not been found except on imported produce, however, *R.dominica* has recently been found breeding in stored grain of UK origin and it will be necessary to monitor the progress of this destructive insect.

Tenebrionid beetles

The presence of an aggregation pheromone common to both *Tribolium confusum* and *T.castaneum* led to the production of commercial lures used in Storgard traps. These have been shown at Slough to be attractive to both male and female *T.castaneum* in laboratory tests (Table III) but there are no reports of large scale field trials

TABLE III Response of mixed sex Tribolium castaneum to Pherocon™ pheromone source over a 15 minute period.

	% Responders	% Non Responders	$\bar{x}$ time to reach target in seconds
Control	50	50	703
Pherocon cap	100	0	146

Curculionid beetles

Schmuff *et al.*, (1984) have determined the pheromone component of *Sitophilus oryzae* and *S. zeamais*, and there appears to be a tentative link with *S. granarius* (Faustini *et al.*, 1982). However, there are no reports of field trials and these will be dependant upon supplies of synthetic material.

Silvanid/Cucujid beetles

A complex series of seven macrolide lactones has been described by Pierce *et al.*, (1984). These are variously produced by a range of beetle species including:- *Oryzaephilus surinamensis*, *O. mercator*, *Cryptolestes ferrugineus*, *C. turcicus* and *C. pusillus*. Although described as aggregation pheromones produced by males and attracting both males and females, it is difficult to understand the selective advantage or function of three separate aggregation pheromones in one species. It is possible that the production of each lactone is determined by specific essential food precursors: biosynthetic studies may elucidate the relationship between each pheromone component and its function. Further studies could show that some of the components have a function in sexual behaviour. Evaluation of macrolides in traps against *C. ferrugineus* have shown that there is an attractant effect in practice (Loschiavo *et al.*, 1986).

Collaborative work between the Slough Laboratory and Oxford University has pioneered the use of the electroantennogram (EAG) technique for studying the response of *O. surinamensis* to pheromones and food volatiles (Chambers *et al.*, 1986). EAG studies together with pitfall bioassays have demonstrated dose responses to synthetic macrolides in *O. surinamensis*. Current work at Slough has confirmed the activity of various synthetic macrolides in attracting *C. ferrugineus* and *C. pusillus* (Table IV). It is curious that a synthetic sample of one of these lactones, 5Z-tetradecen-13-olide, has proved to be attractive to *C. pusillus*, whereas the natural material is reported to be inactive in a pitfall bioassay (Millar *et al.*, 1985).

TABLE IV Response of mixed sex Cryptolestes pusillus to synthetic macrolide lactones, 3Z-dodecenolide (VI)[a] and 5Z-tetradecen-13-olide (VII)[a] in a two-choice pitfall bioassay.

LACTONE	Dose (ng)	% Response in pitfall. Control	Treated
VI	2000	11	77
VII	2000	12	70
VII	100	30	56
VI + VII	2000 + 100	17	76
VI + VII	200 + 10	22	74
VI + VII	20 + 1	9	67
VI + VII	2 + 0.1	21	43

a : Nomenclature as in Pierce et al., 1983

Practical use of pheromones

The value of TDA Pheromone to the food industry has been clearly demonstrated and certain companies place great reliance upon trap catch data. However, the adoption of these traps is far from widespread in the UK and this appears to be due to a number of factors. These include ignorance of the existence of trapping techniques because of poor or inadequate promotion by extension services or trap distributors. Even when companies are aware of the availability of traps they may be put off because of the apparent high cost of purchasing traps and a continuing supply of pheromone lures. There is also a very real problem of interpretation of trapping results: without adequate background information and continuous trapping records, it is impossible to determine treatment thresholds accurately and formulate an integrated control programme. Where this has been done it has been extremely successful but has required considerable input of manpower and expertise.

The value of many of the beetle pheromones is in very specific problem areas. Prevention of damage to tobacco, a very high value commodity, is vital to the industry and there is therefore a considerable economic incentive to adopt pheromone trapping programmes for L.serricorne. We await further documentation of integrated control programmes based on trapping thresholds.

The spread of P.truncatus is of serious concern to many countries who wish to prevent this pest becoming established. The need to detect P.truncatus encouraged the development and adoption of pheromone lures. This is probably the first case of adequate biological and behavioural knowledge being available for a pest at an early stage of problems. It is interesting to speculate on whether quarantine action taken by countries against T.granarium would have been different had effective pheromone traps been available 30 years ago. The message is clear, in order to keep abreast of changing pest status, knowledge of attractant chemicals is required for each candidate pest.

Trapping of insects during storage of bulk cereals is probably the most important area where we can contribute to loss prevention and reduction in use of pesticides. The advance in physical trapping initiated by Loschiavo and developed by Burkholder and others have improved by orders of magnitude the ability of storekeepers to find insects. Cogan et al., (1987) have shown that pitfall and probe traps are more than ten times as effective as conventional spear samples for detection of the major grain pests, O.surinamensis, S.granarius and C.ferrugineus. It is possible to enhance these traps by use of pheromone lures and the effectiveness of some macrolide pheromone components is currently being evaluated at Slough and in Canada. However, it is probable that these lactones will only have a limited sphere of influence in a dense grain bulk, these pheromones are in a very different environment from Ephestia TDA in an open mill or warehouse.

Where it is known that a particular species is a problem, a specific pheromone may have a successful role. But what of the farmer or storekeeper who will not know which species will attack his grain? Should he use one lure for each of O.surinamensis, C.ferrugineus, S.granarius and R.dominica ? Even if all were commercially available, using at least four pheromones may be impractical or too expensive. Furthermore, work at Slough has shown that a UK strain of O.surinamensis produces the same three macrolide lactones as Canadian strains (Pierce et al., 1985) but in different proportions, suggesting that traps for different strains of the same species may need different ratios of components. In addition, further research may show that certain pheromones inhibit the responses of beetles to their own pheromones. Differences in species, strains and commercial practice may mean that a technique successful in one location may be ineffective or inappropriate for another.

It has been shown that for detection of beetles in stores and warehouses a general broad spectrum trap using food attractants can be extremely effective for a wide range of pest species, (Pinniger and Wildey, 1979; Hodges et al., 1985). In practical use, bait bags were more effective than specific pheromone traps, which although more efficient for their target species were ineffective for other pest species present. Even in a laboratory study it has been observed that the attractancy to food volatiles of C.pusillus can be comparable with that of its own pheromone (Millar et al., 1985). Food volatiles derived from carobs have produced attractant responses in many pest species including O.surinamensis, C.ferrugineus, T.castaneum, S.granarius, and Ahasverus advena. Preliminary tests have shown that these volatiles can increase catches in probe traps. It is our intention to evaluate carob volatiles for trap enhancement in cereal bulks in parallel with the macrolide lactones of O.surinamensis and C.ferrugineus. The results from these trials should indicate the relative value of food attractants and pheromones for use in cereal storage.

Full exploitation of these promising chemicals depends on gaining more basic knowledge about insect responses in terms of micro-behaviour and biosynthesis. Furthermore this research should not be restricted arbitrarily to pheromones but should include food volatiles and attractants from any other source. The goal is improved detection, and all research which contributes to our knowledge of insect responses to attractants will benefit food storage practice.

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