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COMMERCIAL GRAIN STORES 1988/89, ENGLAND AND WALES PEST INCIDENCE AND STORAGE PRACTICES - PART 1

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COMMERCIAL GRAIN STORES 1988/89
ENGLAND AND WALES
PEST INCIDENCE AND STORAGE PRACTICE - PART 1

edited by

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CONTENTS

PART 1

PART 2

INTRODUCTION

The successful growth of the cereal industry in the UK, with both wheat and barley production exceeding domestic use, has resulted in an annual exportable surplus of around 6M tonnes. This growth has been almost entirely in the production of wheat, as is demonstrated by comparison of average figures for the years 1965-75 and 1980-88. In England and Wales, average barley production was similar for the two periods - 7.2M and 7.8M tonnes respectively -whilst wheat production nearly trebled, from 4.2M to 11.0M tonnes (Anon, 1977, 1986, 1990).

A consequence of this growth, and membership of the European Community, has been that part of the grain is stored for longer and the average size of off-farm stores is larger (Taylor and Lloyd, 1978; Garthwaite, Chapman and Cole, 1987). The longer storage period has increased the opportunity for the grain to be damaged by insects or mites, whilst the EEC quality standards adopted by the UK for the sale of grain into intervention include the requirement of complete freedom from live pests.

General observation suggests that the industry has been successful in meeting the new standards, using both physical methods (e.g. drying and cooling) and prophylactic insecticide treatments to avoid pest problems.

The existence of insecticide-resistant strains of insects and mites poses a further problem for store managers, and with the continuing need to use insecticide, coupled with the small number of compounds cleared for use on grain, this is likely to become a significant problem. Resistance is a world-wide phenomenon and in the UK has been detected in insects from both farm and commercial stores. Estimates of its frequency in the UK have been somewhat speculative because they have been based mostly on data from stores with a pest problem rather than a representative random selection of stores. Because each commercial store accepts grain from several farms, and it needs only one batch of grain with undetected insects to cause an infestation, the likelihood of infestation (in the absence of remedial action) is greater for commercial stores than farms. The same is true for the occurrence of resistant strains. Since the major pests rely on man to transport them from country to country and from store to store, the first step to prevent their establishment in a store is adequate inspection of grain upon intake.

MAFF is undertaking a rolling programme of information gathering exercises to determine the extent of resistance in stored product insects and mites. The first two, undertaken by staff of the ADAS Central Science Laboratory and the ADAS Wildlife and Storage Biology group, have been concerned with stored cereal grain and have provided not only much-needed data on the distribution of pests and the incidence of resistance, but also a comprehensive description of current storage practice.

The first exercise investigated farm grain stores and entailed visits to a random sample of 742 farms in England during 1987 (Prickett, 1988; Muggleton and Prickett 1990). The second looked at commercial grain stores in England and Wales, with 171 sites visited during 1988/89 and 283 individual stores checked for the presence of pests. This exercise was jointly funded by the Home-Grown Cereals Authority and MAFF, and the results are presented in this report. Although MAFF carries out regular surveys of stores to confirm that pesticides are used safely, this is the first time that such a comprehensive view of commercial grain stores has been obtained.

For ease of use the report has been bound in two parts, with the text in the first part and the tables in the second part. Chapters 2 and 3 provide brief commentaries on the data collected in response to each question on the fact sheets. Chapters 4 to 7 give a more detailed breakdown of the data relating to pest incidence, and Chapters 8 and 9 give the results of the pesticide resistance tests carried out on the samples of beetles and mites collected during the exercise. These latter Chapters may contain some information which will be of interest to the specialist, rather than the general, reader. The final Chapter provides a brief summary of the exercise.

CHAPTER 1

MATERIALS AND METHODS

A J Prickett

1.1 Definitions

A "commercial grain store" was defined as one belonging to an organisation/person that traded (bought and sold), or stored, grain but excluded those whose major commercial activity was producing a finished product; growers of grain and producers of feed were also excluded. Government owned IBAP stores were included since they were under a similar management.

Throughout this report, a "site" refers to a geographical location used by an organisation/person to store grain and a "store" refers to a discrete grain storage structure at a site.

"Grain" refers to cereal grain, and excludes rape.

1.2 Selection of sites

A list of companies storing grain on a commercial basis was supplied by the HGCA through the Regional Cereals Officers. The Companies were contacted to ask for their co-operation; to identify sites; and to obtain a provisional estimate of the number of grain stores. IBAP supplied details of Intervention stores. A total of 195 sites were identified, with 483 discrete storage structures. The intention was to visit all sites with a storage capacity of more than 1,000 tonnes and to inspect up to 4 stores at each site.

1.3 Sites visited and stores inspected

Of the initial 195 sites, 2 fell outside the definition of a commercial grain store, 8 had ceased trading, and 6 were excluded as their capacity was less than 1,000 tonnes. Thus the final number of commercial sites identified was 179. Of these, 7 declined to participate and 1 could not be contacted: the remaining 171 sites were visited.

The exclusion of outside bins and silos from inspection, on safety grounds, resulted in no inspections at 9 sites which had only this type of grain storage. A further 5 sites were not inspected for other reasons. At the remaining 157 sites, a total of 283 stores were inspected.

The visits were intended to take place from October to December 1988 but the final inspections were not completed until the end of March 1989 (Table 2). As the winter was very mild, the continuation of insect trapping into the January-March period (at 17 sites), when the insects are usually at their least active, has probably had little effect on whether or not insects were found.

The distribution of sites is shown in Figure 2 and Table 1 and, as might be expected, the largest contribution of sites came from the Eastern Region. Throughout this report, the 5 MAFF regions - Northern, Midlands and Western, Eastern, South Eastern, and South Western - are abbreviated to N, M+W, E, SE and SW respectively (Figure 1).

1.4 Collection of data

A fact sheet was designed as 2 parts, Part A to cover the site being visited, and Part B to cover the store(s) being inspected (Appendices 1 and 2). Thus one Part A and up to four Part Bs would be completed for each site. Questions were asked under headings which included: type of grain store; grain storage practice; insecticide use, rodenticide use; awareness of pest presence and methods of monitoring for pests; and a checklist of major pest species to be recorded and detection methods to be used was appended. The fact sheets were completed by an ADAS Adviser in consultation with the store manager.

1.5 Inspections

To standardise inspections, a protocol (Appendix 3) was produced describing the use of bait bags, pitfall traps and probe traps, and setting out the duration of each visit. For the same reason the pest species to be recorded were limited to those listed on the fact sheet. The inspection of outside bins and silos was excluded on safety grounds, and at sites where this was the only type of storage only Part A of the fact sheet was completed.

1.6 Collection of insect and mite samples

Insects and mites were collected either as a result of searching or sieving the grain or by their capture in bait bags, pitfall and probe traps, or by a combination of these methods. After preliminary sorting at the site, or in the laboratory, all insects and mites listed on the checklist in Part B of the fact sheet were sent to the Slough Laboratory for final identification. The specimens were required to be alive on arrival at Slough, and collecting tubes with food, and padded envelopes, were given to the Advisers to try and ensure a high survival rate in transit. On arrival at Slough, cultures of beetles

(*Oryzaephilus*, *Cryptolestes*, *Sitophilus* and *Tribolium*) and mites (*Acarus*, *Glycyphagus* and *Tyrophagus*) were set up for subsequent resistance testing.

The common names of insects and mites mentioned in this report are given in the glossary.

Fig 1. **MAFF Regions**

N = Northern
M+W = Midlands and Western
E = Eastern
SE = South Eastern
SW = South Western

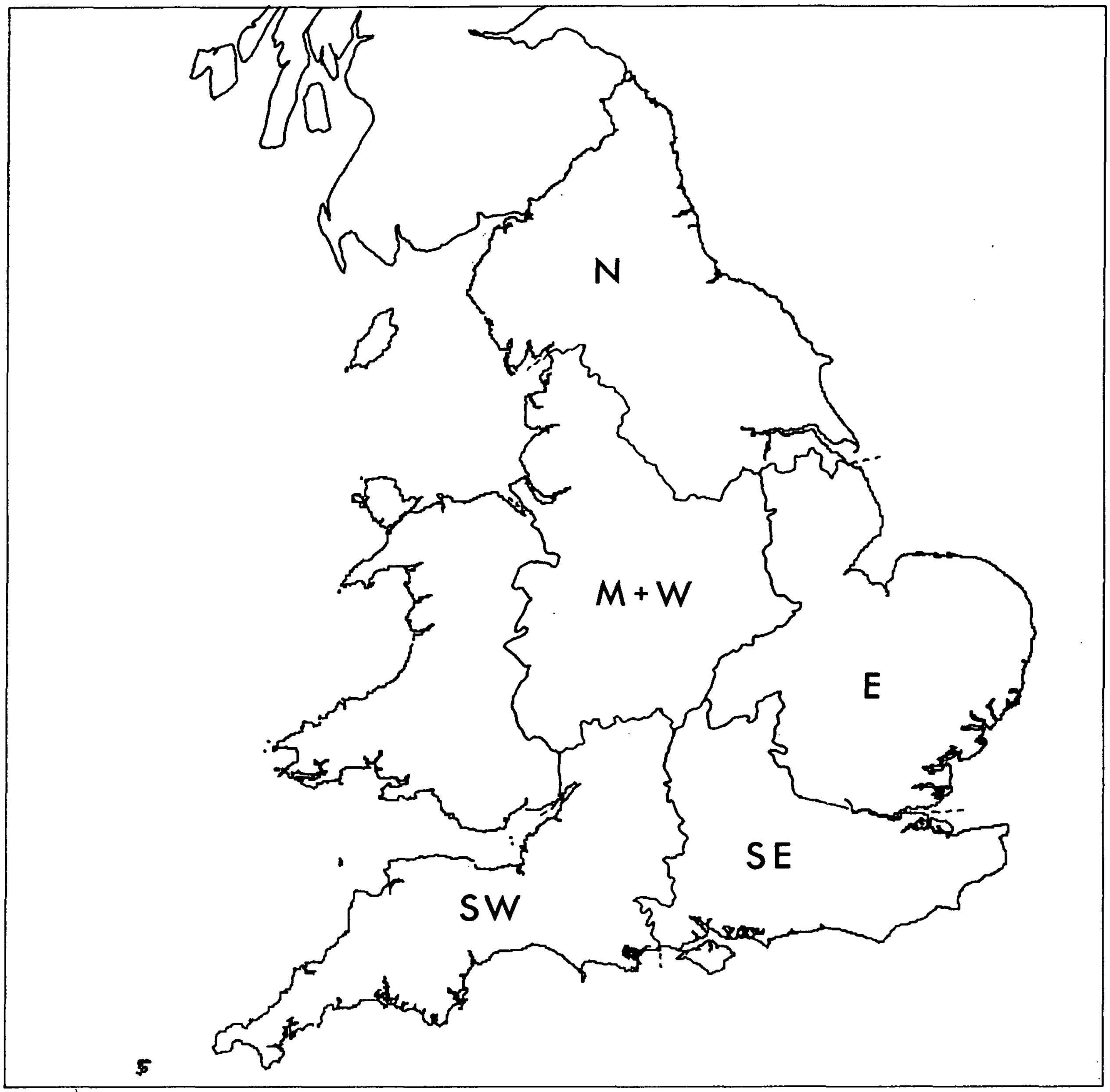


Fig 2. Distribution of the 171 Commercial Grain Store sites visited

CHAPTER 2

RESULTS FROM PART A OF THE FACT SHEET - SITES VISITED

A J Prickett

These results, from 171 sites, are presented in Tables 1 - 49 and provide an overall picture of commercial grain storage practice.

2.1 Description of sites

Sites were classified as one or more of the following categories:- commercial trading; co-operative; Government owned; associated with a port; or 'other type' (Table 1). The majority (76.6%) were purely commercial trading and a further 8.3% included this category, giving 84.9% overall. Co-operatives operated at 14.1% of sites, and 4.7% were associated with ports.

To avoid inadvertently identifying specific sites, given the small number of sites in most of the category/region groups, in the rest of the tables of results, data are given for each of the regions but not for the site categories.

At 69% of sites, storage was the sole activity (Table 3). The most common other activities at the remaining sites were seed cleaning and milling. Infestable commodities other than cereal grain had been stored at 62.4% of sites in the last 12 months; with rape at 46.5% and peas or beans at 42.9% (Table 4).

The intended fate(s) of the grain currently in store was specified at 161 sites (Table 5) and the most common were export (66.5%); feed mill (65.2%); flour mill (41.0%) and malting (37.3%). Grain was in Intervention at 29.8% of sites.

There was no cereal grain present at 4 sites when visited, and the source of the grain currently in store was not specified at 2 sites. Of the remaining 165 sites, 98.2% held home-grown grain from farms, 32.7% held home-grown grain received from other stores, and 5.5% contained imported grain (Table 6). **The percentages total more than 100% because some sites held grain from more than one of these sources.** One site (0.6%) held only imported grain, 4.8% held both imported and home-grown grain, and 94.5% held only home-grown grain. The home-grown grain was received only from farms at 66.6% of sites, from farms and other stores at 31.5%, and only from other stores at 1.2%.

2.2 Site capacity and content

The frequency of sites with floor-stores, internal bins, external bins and combinations of these 3 types of storage are given in Table 7, and the total storage capacities in Table 8. Tonnages have not been rounded in this report.

The total grain storage capacity at the 171 sites was 4,331,880 tonnes, of which 83.2% was floor storage, 3.6% internal bins and 13.3% external bins. Of the 8 known sites that did not participate in this exercise, 5 had a total capacity of 133,940 tonnes and if it is assumed that the 3 sites of unknown capacity had the average capacity of 25,000 tonnes each, then the total capacity for all sites was 4,540,820 tonnes. Thus the capacity of the sites visited probably represented 95.4% of the total.

The quantity of grain present at the time of visits totalled 2,312,388 tonnes, including 1,205,893 tonnes of wheat and 1,096,432 tonnes of barley (Table 9). Other grain present was 8,235 tonnes of oats, 1,360 maize and 468 rye. Although the grain present represented only 53.4% of capacity, its distribution between floors, internal and external bins (80.1, 3.8 and 16.1% respectively) was very similar to the capacity percentages quoted above.

Raising the data on the basis of the average content, the estimated total grain present at the 179 known sites was 2,420,572 tonnes.

Grain throughput data was requested for the last 12 months or, if this was not available, for the last trading year. All but 6 sites disclosed their throughput and the total obtained was 4,480,713 tonnes, approximately twice the quantity in store (Table 10).

Raising the data on the basis of the average throughput, the estimated total throughput for the 179 known sites was 4,860,897 tonnes.

The combined raised estimates for content and throughput was 7,281,469 tonnes. This is equivalent to one-third of the grain (wheat and barley) produced and imported in 1987/88, which were 21.2M and 2.4M tonnes respectively (MAFF/HGCA data).

2.3 Intake and inspection

Grain was delivered to the majority of sites (91.0%) by contractor's lorry, with 27.1% using only that method (Table 11). Whereas 44.0% used their own lorries, only 2 sites did so exclusively. Similarly, 61.4% of sites received grain by tractor/trailer but only 3 sites used no other forms of transport.

91.6% of sites examined the grain for infestation upon intake (Table 12) with vacuum sampling being slightly more common than spear sampling (55.3 and 50.7% of examining sites respectively, Table 13). 4% of sites that checked for infestation used neither vacuum nor spear.

The number of samples of grain taken per lorry or trailer load is shown in Table 14. No account was taken of the size of either the load or the sample. The data show a broad range from 1 to >8 samples per unit for each type of transport with, on average, fewer samples from trailers and greater numbers from contractor's lorries, possibly reflecting the relative size of the loads.

The level of pest numbers acceptable in grain upon intake (Table 15) differed between insects and mites: whereas 89.8% of sites had a nil tolerance for insects, 79.5% would accept small numbers of mites.

Over half the sites (59.3%) had rejected grain because of infestation in the last 12 months (Table 16). The average quantity rejected per site was 214 tonnes. Of the sites that had rejected grain, 80.1% had rejected grain from farms and 23.2% had rejected grain from other stores, giving a ratio of 3.5:1, which is very similar to the 3:1 ratio for the source of grain given in Table 6.

2.4 Grain cleaning, drying and cooling

Grain cleaners had been used at 59.2% of sites in the last 12 months (Table 17). Aspirated sieve cleaners were the type most widely used - 79.0% of sites that used a cleaner - with aspirated cleaners and sieve cleaners used at 21.0 and 20.0% of cleaning sites respectively. Some sites used more than one type of cleaner.

Grain dryers had been used at 65.7% of sites (Table 18). Of the sites that had dried grain, the majority (94.6%) did so by heated continuous or batch dryers, with 87.4% using only this method; 6.3% using (near)-ambient drying also; and the remaining 0.9% (1 site) using a dehumidifier as well as heating. Drying with (near)-ambient air was the only method used at 5.4% of drying sites, giving a total of 11.7% using this method.

Almost all sites (90.6%, Table 19) had cooled grain in the last 12 months, of which 99.4% used a ducted or ventilated system and the remaining 1 site used multiple spearators. 4 sites used refrigeration. Table 20 shows that the 90.6% of sites that cooled grain accounted for 96.9% of total storage capacity, and that at these sites an overall 84.9% of capacity could be cooled at one time.

The methods of fan control at sites where grain was cooled are given in Table 21. Fans were controlled only manually at 71.2% of sites; manually and automatically at 13.1%; and only automatically at 15.7%. Thus the totals for manual and automatic control are 84.3 and 28.8% respectively. The most common form of automatic fan control was a combination of thermostat and humidistat (17.0%) and only 2% used a differential thermostat.

2.5 Insect and mite control

Half the sites (49.4%) said that they had had neither insect nor mite infestations during the last 12 months (Table 22). One-quarter of the sites (23.5%) reported having had an insect infestation within this period and 39.9% a mite infestation. When asked which species they believed had been present in the insect infestations, managers at 82.5% of these sites specified one or more of the beetles *Oryzaephilus*, *Sitophilus* or *Cryptolestes* (5.0% did not name the insects). The individual figures for each of these 3 beetles were 45.0%, 40.0% and 15.0% respectively (Table 23).

Site managers' views as to the seriousness of infestations by insects or mites, if they were to occur, were categorised as 'very serious', 'serious', 'of some concern' or 'of little concern' (Table 24). Almost all managers (94.1%) would consider an insect infestation to be very serious or serious and the corresponding figure for mite infestation was 58.2%. When managers were asked which insect they would consider to be the most significant potential pest, of those who answered, 64.9% specified *Oryzaephilus*, 27.8% *Sitophilus* and 7.9% *Cryptolestes* (Table 25). 'Any grain pest' was the answer given by 7.3% of site managers. Although the question called for a single answer, some managers specified more than one insect, resulting in 174 answers from 151 site managers. Nevertheless, the 3 most often specified insects and their frequency ranking were the same (perhaps not surprisingly) as those said to have been present in infestations within the last 12 months.

The insect detection methods used at sites in the last 12 months are shown in Tables 26 and 27. Most sites (94.1%) used some form of insect detection but

7.1% carried out only visual inspections. Grain sampling was carried out at 83.5% of sites, with 78.8% using spears and 20.0% vacuum. Insect trapping occurred at 38.2% of sites, with probe traps, pitfall traps and bait bags being used at 27.6%, 19.4% and 15.3% respectively. More than one method of trapping was used at 18.8% of sites.

Insecticide had been used to treat the fabric of stores or machinery in them at 85.8% of sites during the last 12 months. The great majority were prophylactic treatments with only 7.5% of treatments carried out because an infestation had been detected within the past 12 months (Table 28). Pirimiphos-methyl was the most commonly used insecticide (75.2% of treated sites, Table 29), with chlorpyrifos-methyl and etrimfos each used at 13.1% and methacrifos at 4.1% of treated sites. Pyrethroids - either alone or formulated with organophosphorus compounds - were used at 13.8% of treated sites.

All or part of the grain had been treated with insecticide at 71.6% of sites: 67.5% used contact insecticide and 7.7% had fumigated (Table 30). Contact insecticides were most often used for prophylactic reasons (two-thirds of treated sites) whereas fumigations were mainly used because of the known presence of pests. The quantity of grain treated in the last 12 months was specified for 113 of the 121 sites that treated, and the total for these sites was 1,530,321 tonnes (Table 32). This total consisted of 639,409 tonnes of wheat, 878,612 of barley and 12,300 tonnes of oats. Comparison of the total grain treated with the total grain in store plus the total throughput (at 159 sites where all 3 values were specified) gives a figure of 23.0% for the overall proportion of grain treated with insecticide.

To put this figure of 23.0% into perspective, the quantity of grain passing through commercial sites is equivalent to one-third of the total home-grown and imported wheat and barley (see 3.2). **Thus the total treated at commercial sites represents less than 8.0% of all home-grown and imported grain.**

As with fabric treatments, pirimiphos-methyl was the most commonly used grain protectant (72.7% of sites that treated grain), followed by chlorpyrifos-methyl (20.7%), etrimfos (12.4%) and methacrifos (6.6%): fumigants had been used at 10.7% of treated sites (Table 33). Of the sites which treated grain with contact insecticide, 61.4% admixed bulks by machine, 28.9% used surface treatments and 17.5% used other methods (Table 34).

The majority of fabric and grain treatments with contact insecticide were carried out by site staff; those by other operators were mostly fabric treatments (Table 35).

Overall, 94.1% of sites had treated the fabric and/or the grain during the 12 months (Table 36) and 84.4% of these sites had used pirimiphos-methyl (Table 37).

2.6 Rodent control

Rodents were said to have occurred at 71.9% of sites during the last 12 months (Table 38). The occurrence of mice (66.1% of sites) was slightly greater than that of rats (60.2%), but 54.4% of sites reported that both rats and mice had been present.

Rodenticide treatment had been undertaken at all but 4 sites (97.7%) during the last 12 months (Table 39) and the rodenticides and formulations used are shown in Table 40. At 29.3% of these sites the rodenticide was not identified. Contractors carried out treatments at 62.7% of treated sites, site staff at 39.8%, and the local authority at 7.8% (Table 41). The average cost of treatment was £408 per site, being greater where contractors were used rather than site staff, and less for local authority. However, no allowance has been made for the relative sizes of sites, which would be expected to be reflected in the cost (Table 42).

When asked to rate the rodenticide treatments as very effective, partially effective, or ineffective, managers at 62.4% of sites said very effective, 37.6% partially effective, and none said ineffective. There was no difference in perceived effectiveness between sites treated by site staff and those treated by contractors (Table 43). Similarly, comparing the rodenticide with effectiveness, both at sites using only one particular compound and at sites using that compound in combination with others, showed no significant difference in perceived effectiveness between rodenticides (Table 44).
As well as using rodenticide, 29.2% of sites had used other methods of rodent control (Table 45).

2.7 Bird Control

Just over half the sites (53.2%) reported having had birds present in the last 12 months, with pigeons - including collared doves - at 42.1%, sparrows at 22.8% and starlings at 2.3% of sites (Table 46).

Bird control had been undertaken at 32.9% of sites, consisting of 51.5% of sites that had had birds present and 12.5% of those that had not (Table 47). The methods used were mostly proofing and shooting (each carried out at 48.2% of control sites) with baiting at 8.9% and other methods at 7.1% (Table 48).

Managers considered their method of control to be very effective at 50.9% of sites, partially effective at 38.2% and ineffective at 10.9%. A break-down of method, operator and effectiveness is given in Table 48, but the numbers are too small to make meaningful comparisons between all of these. However, at sites which used only one method of bird control and the effectiveness was ascertained, none of the managers at the 22 sites where proofing was used considered it to be ineffective; baiting was ineffective at 1 out of the 3 sites; and shooting was said to be ineffective at 4 out of 21 sites.

2.8 Advice

When asked where advice on grain storage had been sought and/or obtained in the last 12 months, 56.7% of sites specified sources of advice on pest control and 33.9% advice on other aspects of grain storage, with a total of 66.1% gaining advice (Table 49). Of the 97 sites which gained advice on pest control, the major sources were chemical companies (40.2%) and ADAS (36.1%) whilst consultants advised 11.3% and 32.0% specified various 'other sources'. Other advice was supplied by ADAS to 44.8% of the 58 advised sites, with chemical companies, agricultural companies and consultants each advising approximately 14.0%; 'other sources' were mentioned at 46.6%. Overall, ADAS (either staff or leaflets) gave advice to 28.1% of all sites, amounting to 42.5% of the 113 sites which specified sources of advice.

CHAPTER 3

RESULTS FROM PART B OF THE FACT SHEET - STORES INSPECTED

A J Prickett

These results, from 283 stores at 157 sites, are presented in Tables 50 - 87. They give details of the frequency with which potential pests were detected during the inspections and the steps taken at the stores to prevent them from developing into problems.

3.1 Stores inspected

A maximum of 4 stores were inspected at each site and the distribution of these stores is shown in Table 50. The categories of sites visited but not inspected, mostly because only external bins were present, are given in Table 51.

The total capacity of the stores inspected was 3,026,690 tonnes, representing 69.9% of the capacity of the 171 sites visited, and 80.7% and 77.7% of the floor-storage and internal bin capacities respectively (Table 52). The Eastern Region accounted for 42.3% of the capacity inspected.

Floor-stores only were inspected at 121 sites, floor-stores and internal bins at 23, and bins only at 13 sites, with a total of 246 floor-stores and 958 bins. The fabric of the bins was mostly metal (44.5%) or concrete (37.6%) accounting for 24.2 and 62.1% of total bin capacity respectively (Table 53). Over half (57.3%) of floor-stores were purpose-built, 23.2% were hangars and the rest (19.5%) were described as 'other type' (Table 54). The total capacity of the purpose-built floor-stores was 1,195,800 tonnes, that of hangars was 903,600, and 'other type' was 806,545 tonnes. Most floor-stores (82.5%) had grain walling, which was commonly metal (48.8%) or wood (26.1%, Table 55). Of those stores which had grain walling, and had grain present at the time of visit, 85.0% had grain surcharged above the walling (Table 56).

3.2 Content of stores inspected

The stores inspected contained 1,680,786 tonnes of grain, which was 72.7% of the total for all 171 sites visited (Table 57). Floor-stores contained 1,604,168 tonnes and 76,618 tonnes was in bins, made up of 854,097 tonnes of of wheat, 819,005 tonnes of barley, and the remaining 7,684 tonnes was oats, maize and rye. Nearly half (46.3%) of the grain was in the Eastern Region. At the time of inspection, 19 stores contained no grain.

Potentially infestable commodities other than cereal grain were present in 24.3% of stores, which included 11.1% containing rape, 13.2% peas or beans, and 7.1% other commodities (Table 58). 72.1% of stores contained only cereal grain and 3.6% were empty.

3.3 Grain cooling and grain monitoring

Of the stores that contained grain, 84.7% had a cooling system and, of these, 93.7% had cooled the grain currently in store (Table 59). Thus 79.4% of stores with grain had cooled it, a slightly lower figure than the 90.6% of sites which had cooled grain in the last 12 months (Table 19).

The temperature of the grain was measured in 80.5% of stores containing grain (Table 60). Fixed sensors were used in 47.8% of monitoring stores, with 13.0% also using spot measurements; the other 52.2% relied only on spot measurements. The grain temperature had been checked on intake in 76.6% of stores that monitored temperature, giving a percentage of 61.7 for all stores with grain. After intake, of those stores that measured the temperature upon intake and/or subsequently, 69.9% checked it weekly or more frequently; 19.1% monthly; and 11.0% less than monthly or never.

Nearly all stores (97.3%) measured the moisture content of the grain and all but one of these checked it upon intake (Table 61). Meters were used in 98.0% of monitoring stores and ovens in 24.6%. After intake, of those that measured the moisture content upon intake and/or subsequently, 36.6% checked it weekly or more frequently; 35.4% monthly; and 27.9% less than monthly or never.

Grain was checked for pests in 92.0% of stores, with 94.1% of these checking on intake, giving a value of 86.6% for stores with grain having checked for pests on intake (Table 62). After intake, of those that checked, 46.1% did so weekly or more often; 35.2% monthly; and 18.6% less than monthly or never.

Grain was sampled for pests by spear or vacuum in 79.9% of stores containing grain (compare with Table 27 for sites), with spears used in 76.0% and vacuum in 12.2% (Table 63).

Insect trapping, using probe traps, pitfall traps or bait bags, had been carried out in 26.4% of stores containing grain. These three methods were used in 22.0, 9.8 and 6.3% of stores respectively. Grain sampling and/or trapping occurred in 80.7% of stores; sieving only at 0.4%; visual inspections only at 9.4%; other methods at 1.2%; and no inspections at 8.3%.

3.4 Stores where managers were aware of potential pests

For each of the stores inspected, the managers were asked whether they were aware of any potential pests in them. Insect pests were said to be present in 5.0% and mites in 22.5%; rodents were reported in 55.2% and birds in 28.9% (Table 64). Overall, one or more of these pests were believed to be present in 69.4% of stores.

3.5 Insecticide use in stores

The fabric of the store, or machinery in it, had been treated with insecticide in 78.6% of stores during the last 12 months (Table 65). This figure is slightly lower than the 85.8% for sites (Table 28). Of the stores that were treated, 95.0% did so for prophylactic reasons. The insecticides, and the percentage of stores in which each was used (Table 66) reflected the pattern shown for sites (Table 29), with pirimiphos-methyl having been used in 74.5% of treated stores.

The questions on whether grain was treated with insecticide differed between stores and sites: whereas the question relating to sites concerned any grain treated in the last 12 months, the question for stores related only to grain currently in the store. Thus although 71.6% of sites had treated grain (Table 30), only 50.0% of stores had done so (Table 67). The grain was treated because of known infestation in 9.9% of stores containing grain, or 19.8% of treated stores (Table 68). Pirimiphos-methyl was most commonly used on grain (71.0% of treated stores) with chlorpyrifos-methyl being the next most common insecticide (22.9%, Table 69). Insecticide was applied to grain by mechanical devices in 64.5% of stores that admixed (some of these stores also used other methods); 16.9% admixed bulks only by other methods; and 18.5% used only surface treatments (Table 70). Sprays were used in the majority of bulk treatments by machine, whereas dusts were used in most applications by hand and surface treatments.

Overall, the fabric and/or grain was treated with insecticide in 85.4% of stores (Table 71). Of the stores containing grain, 35.5% treated only the fabric; 42.4% treated both fabric and grain; 7.3% treated only the grain; 0.4% treated the grain but it was not known whether the fabric was treated; and the remaining

14.5% were untreated. Pirimiphos-methyl was used in 81.3% of treated stores, either on the fabric or grain; chlorpyrifos-methyl in 15.8%; etrimfos in 11.7%; and pyrethroids (including mixtures with organophosphorus compounds) in 8.8%; other insecticides were each used in less than 4.0% (Table 72).

3.6 Insects and mites detected during inspections

Stores were inspected for the presence of those insects and mites which have the potential, if no remedial action were taken, to cause economic loss, either by damaging the grain or by their presence leading to the rejection of grain offered for sale. No account was taken of the number present: if even one live insect was found, it counted as a 'detection'. **The following should therefore not be read as indicating heavy infestations in stores.**

The three major beetle pests - *Oryzaephilus surinamensis* (saw-toothed grain beetle), *Cryptolestes ferrugineus* (rust-red grain beetle) and *Sitophilus spp.* (grain weevils) - were detected at 39.5% of sites and in 26.5% of stores (Table 76).

O. surinamensis occurred at 19.7% of sites and in 14.5% of stores (Table 73). In 12.4% of stores the insects were detected in the grain; in 1.8% they were found on the structure but not in the grain; and in 0.4% (1 store) it was unclear whether they were found in grain or on the structure.

C. ferrugineus was found at 17.2% of sites and in 10.6% of stores (Table 74).Detections in grain accounted for 6.7% of the stores, with 2.1% for structure but not grain, and 1.8% unknown where found.

Sitophilus spp. were detected at 22.3% of sites and in 13.1% of stores (Table 75). The species were identified for 31 of the 39 stores with *Sitophilus: S. granarius* occurred in 29 stores and *S. oryzae* in 3 (1 store had both species). *Sitophilus* was found in grain in 9.2% of stores; on the structure but not in the grain in 2.5%; and in the remaining 1.4% it was uncertain where they were found.

Of the 75 stores in which *O.surinamensis*, *C. ferrugineus* or *Sitophilus spp.* were detected, 23 had more than one of these 3 pest species; 21 had only *O. surinamensis*; 11 had only *C. ferrugineus*; and 20 only *Sitophilus spp.*

Beetle pests generally associated with mould - *Ahasverus advena* (foreign grain beetle), *Typhaea stercorea* (hairy fungus beetle) and *Cryptophagus spp.* (mould beetles) - occurred at 26.1% of sites and in 18.4% of stores (Table 80). These may well be underestimates for two reasons: firstly, some occurrences of *A. advena* and *T. stercorea* were noted on the fact sheets but not confirmed by laboratory identification, and these areexcluded from the above figures; secondly, *Cryptophagus spp.* were not included in the check-list of pests in the fact sheet, but were collected sufficiently frequently to warrant their inclusion in this report.

A. advena was positively identified from 7.6% of sites and 4.2% of stores, with unconfirmed occurrences at a further 1.3% and 0.7% respectively (Table 77). This species was found in the grain in all 10 stores where both the identification and the method of detection were certain.

T. stercorea detections were confirmed at 8.9% of sites and 6.0% of stores: a further 5.7% and 3.5% occurrences respectively were unconfirmed (Table 78). Of the 17 stores where the identification was confirmed, the beetles were found in the grain in 14, on the structure but not in the grain in 2, and unknown where in the remaining 1 store.

Cryptophagus spp. were collected from 38 stores (13.4%) at 31 sites (19.7%). Insects from 22 stores were identified to genus only, and to species for 16 stores: a total of 10 different species were noted, and these are listed in Table 79. The relative frequencies with which these insects were found in the grain or on the structure are not known.

A. advena, T. stercorea or *Cryptophagus spp.* were found in combination in 4.6% of stores, *A. advena* alone in 1.4%, *T. stercorea* in 2.1%, and only *Cryptophagus spp.* in 10.2%.

Spider beetles (Ptinidae) were quite widespread, being detected at 49.7% of sites and in 36.0% of stores (Table 81). Although not all of these were confirmed by laboratory identification, their appearance is sufficiently distinctive for it to be unlikely that any were incorrectly recorded. Three species were identified and *Ptinus fur* was the most common, recorded in 25.1% of stores, followed by *P. tectus* in 7.8% and *P. pusillus* in 1.1%: more than one of these species occurred in 5.0% of stores. Detections in 7.1% of stores were not confirmed. Beetles were found in the grain in 29.3% of stores, on the structure but not in the grain in 4.9%, and unknown where in 1.8%.

Three moth pests were recorded - *Ephestia elutella* (cacao moth), *Endrosis sarcitrella* (white-shouldered house moth) and *Hofmannophila pseudospretella* (brown house moth). Unfortunately, only about half of the moth detections were confirmed by identification, so that of the 26.8% of sites where moths were recorded, 14.7% were confirmed and 12.1% were not (Table 82). Similarly, of the 17.3% of stores reported to have moths, 9.2% were confirmed and 8.1% were not. Of the stores where moths were identified to species, *Hofmannophila* occurred in 4.9%, *Endrosis* in 3.5% and *Ephestia* in 1.1%. Although the numbers are small for stores where both the species of moth and the method of detection were known, they indicate a greater tendency for *Endrosis* and *Ephestia* to be found in the grain compared with *Hofmannophila*. *Endrosis* was detected in the grain in 8 out of 9 stores and *Ephestia* in 2 out of 2, whereas *Hofmannophila* was found in the grain in only 1 out of 10 stores.

Psocoptera (psocids or book-lice) were recorded at 65.0% of sites and in 54.8% of stores, with identifications confirmed for 56.7 and 45.9% respectively. Seven species were identified and these are listed in Table 83. The most common species were *Lepinotus patruelis* (28.6% of stores) and *Lachesilla pedicularia* (25.4%) with the frequency of each of the other 5 species being less than 6.0%. Psocids were detected in the grain in 35.7% of stores and on the structure but not in the grain in 7.8%.

Mites of the genera *Acarus*, *Glycyphagus* or *Tyrophagus* were common, occurring at 87.3% of sites and in 81.3% of stores, although these figures include 7.6 and 8.1% respectively where the mites were not positively identified (Table 84).

Acarus spp. were found in 59.4% of stores, with *A. siro* identified in all but one of these (59.0%, Table 85). The two other species identified were *A. farris* (1.8% of stores) and *A. immobilis* (1.4%). *Glycyphagus spp.* were identified from 51.9% of stores - *G. destructor* accounted for 51.2% and *G. domesticus* the remaining 0.7% (two stores). *Tyrophagus spp.* occurred in 25.1% of stores and three species were identified. *T. longior*, *T. putrescentiae* and *T. palmarum* were recorded from 15.9, 12.0 and 1.4% of stores respectively: a sample from one store was identified only to genus.

In the 73.2% of stores where the mites detected were identified, 45.9% had more than one of the three mite genera, 15.5% had only *Acarus*, 11.0% only *Glycyphagus* and 0.7% (two stores) had only *Tyrophagus*.

3.7 Rodents and birds detected during inspections

Rodent presence was recorded on the basis of animal sightings, droppings or other physical signs. Mice were detected at 72.6% of sites and in 61.1% of stores, whilst rats were noted less frequently, at 40.8% of sites and 33.2% of stores (Table 86).

Both rats and mice were detected at 34.4% of sites, mice only at 38.2% and rats only at 6.4%, giving an overall 79.0% of sites with either rats or mice. The figures for stores were 23.0% with rats and mice, 38.2% with only mice and 10.2% with only rats, thus either rats or mice were detected in 71.4% of stores.

This 71.4% is somewhat higher than the 55.2% of stores where the manager was aware of the presence of rodents (Table 64) and a comparison was made between detection and awareness (Table 87). In this latter table the percentage of stores where the manager was aware of rodents is slightly lower (54.4%) because of the inclusion of stores where awareness was not ascertained in the total. Rodents were detected and managers were aware of them in 44.2% of stores; rodents were detected but managers said they were not aware of them in 26.9%; and in 10.2% managers were aware of rodents but they were not detected during inspections. Combining those stores where rodents were either detected or managers were aware of them, gives a total of 81.6%. The corresponding comparison for sites gives a total of 87.3%.

Pigeons, sparrows or starlings were recorded at 59.2% of sites and in 46.3% of stores (Table 86). Pigeons, including collared doves, occurred in 33.6% of stores, sparrows in 23.7% and starlings in 0.7%. The respective percentages for sites were 43.9, 29.3 and 1.3%.

CHAPTER 4

THE DISTRIBUTION OF BEETLES AND MOTHS IN COMMERCIAL GRAIN STORES

A J Prickett

Introduction

This appears to be the first time that such a comprehensive investigation of the occurrence of insects in commercial grain stores has taken place in the UK, covering 283 stores and 157 sites and utilising probe traps, pitfall traps, bait bags, sieving of residues and visual inspections. Wilkin and Hurlock (1986) published some data on insect occurrence, but this was based on information from ADAS advisory visits and as such was biased towards stores with a problem. Similarly the incidence of insects given by Mayhew, Papworth and Rudge (1971) for commercial stores visited in 1968/69 was only for those stores that used insecticide, and was therefore not a random sample.

For safety reasons external bins and silos were excluded from the inspections during the current exercise. This obviously left a gap, but since only 16% of the grain was in such stores this is likely to have had little effect on the overall results.

In the following, insects have been considered in groups: firstly those generally accepted to be primary or major pests - the beetles *Oryzaephilus*, *Cryptolestes* and *Sitophilus* - and then the secondary or minor pests: the fungus beetles *Ahasverus*, *Typhaea* and *Cryptophagus*; the spider beetles *Ptinidae*; and the moths *Ephestia*, *Endrosis* and *Hofmannophila*. The frequencies of these insects are given in the main results section of the report and in tables 73-83, and have not been repeated here unless they are necessary to illustrate a point. The impact of storage practices that are likely to affect the occurrence of insects has been studied, including grain cooling and insecticide use, as well as regional differences and the co-incident presence of different insects.

Oryzaephilus, Cryptolestes and Sitophilus

Laboratory identifications of samples of *Oryzaephilus* and *Cryptolestes* confirmed that they were all *O. surinamensis* (saw-toothed grain beetle) or *C. ferrugineus* (rust-red grain beetle). With *Sitophilus*, *S. granarius* (grain weevil) was identified from 29 stores and *S. oryzae* (rice weevil) from 3; the species was not determined for 8 stores. Given this lack of identity and the low incidence of *S.oryzae*, in the following the *Sitophilus* species are considered together and beetles are referred to by their generic names.

The three major beetle pests - *Oryzaephilus*, *Sitophilus* and *Cryptolestes* - occurred with similar frequency (14%, 13% and 11% of stores respectively) and this was also found to be the case when farm grain stores were investigated in 1987 (4.8%, 4.2%, 4.6% of farms respectively; Prickett 1988). On the basis of these figures it might seem reasonable to consider the three to be equally important, but this would not be in accordance with the response of store managers to two of the questions asked of them. Firstly, of the 40 sites at which the manager said there had been an insect infestation at some time within the last 12 months, *Oryzaephilus* was said to have been present at 45%, *Sitophilus* at 40% and *Cryptolestes* at only 15% (Table 23). Secondly, when asked which insects they would consider to be the most significant potential pests, managers at 151 of the 171 sites answered, with 65% specifying *Oryzaephilus*, 28% *Sitophilus* and 8% *Cryptolestes* (Table 25). With both questions, other minor pests were mentioned also and, since sometimes more than one insect was named, the percentages add up to more than 100%. Presumably the relative lack of comment regarding *Cryptolestes* was either because it tended not to be detected, or was detected but not recognised, or did not occur in sufficient numbers to be considered a pest. Whatever the reason, it would seem desirable for managers to be made more aware of the pest potential of *Cryptolestes*.

The figures given above for insects found in commercial stores and farm stores should not be taken to mean that these insects are generally more common in one type of store than another, because there were important differences between the two investigations and each was a snap-shot in time, giving no information as to the variation from year to year. The farms were visited between April and July 1987, after a particularly cold winter, and the stores were mostly empty awaiting the harvest; the commercial stores were visited between September 1988 and March 1989 and were mostly full.

To look at the regional variations that occurred, the regions have been ranked in Table 88 in the order of frequency with which the three beetles were detected. Data from the farm exercise has been included and there is overall a strong similarity between the rankings in the two investigations. Testing the frequency of beetles in commercial stores against that in farm stores for each of the regions gave a significant and positive correlation coefficient of 0.93 for *Oryzaephilus*, whereas the coefficients for *Sitophilus* and *Cryptolestes* were low (0.76 and 0.60 respectively) reflecting the fact that there were some minor differences in the ranking order for these last two beetles. The correlation for the occurrence of any of the three was 0.92. This comparison of relative frequencies is valid even though, as pointed out above, direct comparison of percentages between farms and commercial stores is not. Wales has been excluded from the Table because only 4 stores were examined - much too small a number for comparative purposes.

Oryzaephilus occurred least often in the N and E regions and most often in the M+W and SW, with frequencies ranging from 6% of stores in the N to 37% in the SW. Both *Cryptolestes* and *Sitophilus* were detected least frequently in the N (1% and 4% respectively) and most frequently in the M+W (24% and 21%). Overall, stores where any of the three beetles occurred were least frequent in the N (12%), followed by the E with 25%: these two regions accounted for two-thirds of the stores examined. The other regions - SE, M+W, SW - were similar with a mean of 38%.

It is tempting to speculate that the frequency of beetles is correlated with the climate, with fewer in the colder parts of the country, but without knowledge of the microclimate at each site this cannot be satisfactorily demonstrated. There is however another possible explanation.

Since almost all sites (98%, Table 6) received grain from farms and most (92%, Table 12) examined it for infestation upon intake, it would seem reasonable to expect the frequency of commercial stores rejecting grain because of infestation (Table 16) to be related to the frequency of beetles in farm stores (Table 88). In fact the inverse was the case: the lower the incidence of beetles in farm stores, the higher the rejection rate, with a significant correlation coefficient of -0.94. The rejection rate varied from 71% of stores in the N to 47% in the M+W. There was a similar negative correlation (coefficient= -0.95) for rejection rates versus beetles in commercial stores, which is in line with the connection between beetles in the two types of store mentioned above. These results suggest that commercial stores in the N and E either examined the grain more closely, or had higher standards, or both, and that the consequence was not only fewer stores with beetles but also the marketing pressure on the supplying farms resulted in fewer farm stores with beetles.

After intake, the two main methods of preventing insect infestation are the cooling of the grain to a temperature below that necessary for the insects to breed, and the use of insecticide. The percentage of stores where the grain had been cooled was similar in all regions (ranging from 84% to 88%) except for the SW where it was 35% (Table 59). To examine the effectiveness of cooling, 196 stores were identified where all three methods of insect detection (probe traps, pitfall traps and baitbags on the grain) had been used during the inspection, and of these, 159 had cooled the grain and 37 had not. *Oryzaephilus* was detected in the grain in 9% of the cooled stores and 27% of the un-cooled ones - a significant difference ($p<0.01$). With *Cryptolestes* and *Sitophilus* there was no such difference ($p>0.05$) and the respective overall frequencies were 9% and 10%.

Looking at it from a slightly different aspect, 140 stores were split into two groups - 89 stores where the temperature of the grain was monitored at least weekly and 51 which were monitored less frequently or not at all. *Oryzaephilus* occurred in the grain in only 1% of the well-monitored stores and 18% of the less-monitored ones, *Cryptolestes* in 6% and 12%, and *Sitophilus* in 10% and 12% respectively. Although in all three cases the frequency of beetles in well-monitored stores was lower, only the figures for *Oryzaephilus* are statistically different ($p=0.001$).

Thus cooling had the greatest impact on *Oryzaephilus* and the least on *Sitophilus*, a difference which is consistent with *Oryzaephilus* having the higher temperature requirement for its development. The apparent lesser effect of cooling upon *Cryptolestes* compared with *Oryzaephilus* is a slight anomaly since its optimum temperature is higher than that of *Oryzaephilus*.

Treatment of the fabric of the store with insecticide occurred in 79% of stores (Table 65) and although there were some regional variations (range 73% - 91%) they were no greater than might be expected from random variation ($p= 0.42$). Attempts to assess the effectiveness of fabric treatments on the basis of the data gathered during this exercise are of limited value because it was not known whether baitbags were placed on part of the structure which had been treated, nor how much of the structure had been treated. Nevertheless, 135 treated stores were compared with 37 untreated ones: there were no statistical differences between these two groups in the frequency with which *Oryzaephilus*, *Cryptolestes* or *Sitophilus* were detected in baitbags.

Some or all of the grain had been treated with insecticide in 50% of stores (Table 67) and, as with fabric treatments, there was some regional variation (range 36% - 65%) but it was again no more than expected from random variation ($p = 0.30$). Stores were selected where all three detection methods for insects in grain had been used during the inspection, and where the grain had been cooled; those where treatments were said to have been done because of infestation were excluded. The resultant 147 stores were split into three groups: 48 where all the grain was treated, 26 where part of the grain was treated and 73 where the grain was not treated.

Oryzaephilus was detected in the grain in 8% of the all-treated group, 23% of the part-treated, and 7% of the untreated; *Cryptolestes* in 4%, 15% and 14% respectively; and *Sitophilus* in 4%, 19% and 10%. One or more of these three beetles occurred in 13% of all-treated stores, 38% of part-treated, and 22% of untreated ones. Statistical comparison of the frequencies showed that for each of the beetles there was no significant differences between the groups and this was probably partly due to the small sample sizes. However, the difference between the 13% of all-treated and 38% of part-treated stores where one or more of the three beetles occurred was statistically different ($p < 0.05$).

The similar results for stores where all the grain was treated and those where none was treated does not mean that the treatments had no effect - insecticides kill insects. If it is assumed that grain was treated at stores where the risk of pest problems was greatest, then one possible explanation is that treating all the grain was successful in reducing the frequency of beetles to the level found in the low-risk (untreated) stores, but did not always eliminate them. Part-treatments appear to have been less successful in that beetles were more commonly found in this group than in either the all-treated or untreated groups. In those stores where live insects were found in the grain in spite of it having been treated, the insecticide could have been applied at any time during the 12 months prior to the inspection and thus may have lost some of its effectiveness. Other possibilities are that the recommended dose was not always achieved or that the treatment was uneven, or the insects were resistant to the insecticide.

During the inspections no estimate was made of the number of insects present in each store. Indeed, the relationship between number caught and number present is unknown and is doubtless complex. A single live insect was sufficient for an insect to be recorded as present. Insects caught in traps or bait-bags were sent to the Laboratory for confirmation of their identity and for resistance testing and the numbers of *Oryzaephilus, Cryptolestes* and *Sitophilus* received were recorded. Given the variability of stores the intensity of trapping will have differed from store to store and thus the number of beetles found (which we must hope was similar to the number received) cannot safely be used to make comparisons between groups of stores. The total number of the three beetles from each of the 75 stores in which they were found was:- 1-5 beetles from 37 stores; 6-50 from 19; 51-500 from 9; more than 500 from 4; and an unrecorded number from the the remaining 6 stores. Of the 75 stores where beetles were found, the managers said they were aware of the presence of insects in only 6. Since the grain was apparently checked at least monthly in 51 of these stores, it would appear that the monitoring methods were not very sensitive.

Ahasverus, Typhaea and Cryptophagus

These three minor beetle pests are fungus-feeders and as such are likely to be associated with grain of a high moisture content. However comparing the frequency of these beetles in 93 stores where the moisture content was checked at least weekly, with 35 where it was not checked, showed no significant difference between the two groups: the frequencies were 19% and 17% of stores respectively. There was also no correlation with either whether the grain was cooled, or the frequency of temperature monitoring. With regard to insecticide use, in stores where all the grain was treated; some was treated; or none was treated, one or more of these three beetles occurred with frequencies of 14%, 27% and 20% respectively. The difference between the all-treated and part-treated stores was not statistically significant but did tend to mirror the results for the major beetle pests discussed previously.

Although no significant correlations were detected between the presence of these beetles and various aspects of storage practice, they did not occur randomly. Taking the frequency of each of the beetles as the likelihood of their occurrence in any one store, the expected frequencies of stores with none, one, two or all three of these beetles, in the 8 possible combinations, were calculated and compared with the observed frequencies. It was found that each of the beetles occurred on their own less often than expected, and that each of the 4 possible combinations of more than one beetle occurred more often than expected (chisquare 26.0 with 4 d.f., P<0.001). Single occurrences were expected in 58 stores whereas they were observed in 39; multiple occurrences were expected in 4 and observed in 13. This indicates, as might be expected, that some stores were more suitable for these beetles and where this was so, more than one type tended to occur. It is likely that these beetles were associated with poor hygiene standards or leaking structure but this information was not gathered during the exercise.

Ptinidae

Of the three species of spider beetles identified (Table 81), *Ptinus fur* was the most common, occurring in 25% of stores, whilst *P.tectus* and *P.pusillus* were found in only 7% and 1% respectively. The picture was similar across all the regions with the exception of the Northern where the incidence was only half that of the other regions.

As with the fungus-feeders, no correlation was detected between the presence of *Ptinus spp* and whether the moisture content was monitored, or whether the temperature was monitored, or whether or not the grain was cooled. Where grain was admixed, *Ptinus* occurred in 30% of all-treated stores and 43% of part-treated ones but again this difference was not significant. The frequency in un-treated stores was 37%.

Comparing the occurrence of spider beetles with that of mould beetles showed that they were found together more often than would be expected by chance (chisquare 21.1, 3 d.f., p< 0.001). From their frequencies of occurrence, they would be expected to occur together in 22 stores whereas the observed number was 37, with a consequent fewer than expected single occurrences. Thus where one minor pest occurs, others are likely to be present.

Ephestia, Endrosis and Hofmannophila

Consideration of the moths was difficult because unfortunately their identity was unconfirmed for half the stores where they were reported (Table 82). However the data were analysed firstly on the basis of stores where the moths were identified, and secondly using all reported occurrences. In neither case was any significant correlation found with the monitoring of moisture content;

grain cooling; temperature monitoring; or insecticide use, although in this latter case moths were present in 9% of stores where all the grain was treated and 22% of part-treated ones.

Incidence of both major and minor pest insects

It has already been pointed out above that the different minor pests tended to occur together rather than randomly, resulting in more stores without these insects than expected; fewer than expected with only one; and more stores than expected with two or more pests. Comparison of the occurrence of the major beetle pests and that of minor pests (beetles and moths) showed a similar picture. With major pests found in 75 stores and minor ones (including unconfirmed identifications) in 144 of the 283 stores inspected, the calculated number expected to have no pests; major ones only; minor ones only; and both types, were 102, 37, 106 and 38 respectively. The observed numbers were 115, 24, 93 and 51, showing more stores than were expected with no and both pests, and fewer than were expected with only major or only minor ones (chisquare 11.9, 3 d.f., $p < 0.001$). This finding may not be surprising, indeed it may be well known, but it appears not to have been documented before.

Summary

i) *Oryzaephilus*, *Cryptolestes* and *Sitophilus* occurred in similar numbers of stores, but managers were most aware of *Oryzaephilus* as a pest, there being little awareness of the pest potential of *Cryptolestes*.

ii) The major beetle pests were less common in the N and E regions, and this was apparently linked to more stringent examination of the grain for infestation upon intake.

iii) *Oryzaephilus* occurred less frequently in stores where the grain was cooled and its temperature monitored frequently.

iv) Admixing part of the grain with insecticide had a limited effect upon the occurrence of beetles, compared with stores where all the grain was treated.

v) Managers were aware of the presence of insects in only 6 of the 75 stores in which the major beetle pests were found, suggesting that more effective monitoring is required.

vi) Insect pests did not occur at random: they tended to occur together.

vii) The general lack of correlations found between pest presence and storage practice was probably in part due to small sample sizes.

CHAPTER 5

THE USE OF SAMPLING METHODS AND STATIC TRAPS FOR THE DETECTION OF INSECTS IN COMMERCIAL GRAIN STORES

P M Cogan

Introduction

Current methods for detecting beetle pests of grain involve either the use of sampling methods or the use of static traps left for a period of time in the grain or associated buildings, before being examined for the presence of insects. Data from the information gathering exercise has been examined in two ways to determine the success of the sampling methods and traps for the detection of storage beetle pests:-

1) To what degree and with what success the detection methods have been incorporated into commercial grain store practices.

2) How successful were the trapping methods used by the WSB Advisers in the information gathering exercise compared with their use by storekeepers.

Insect detection methods used by commercial storekeepers

The methods employed by storekeepers to detect insects are shown in Table 89. As visual inspection is open to subjective interpretation this method has been included in the 'not checked' grouping.

No difference was observed with regard to the detection methods employed by storekeepers at stores where the major beetle pests were or were not present. At both those sites where major grain beetle pests were detected by the WSB Advisers, and those where the pests were not detected by the WSB Advisers, there was a close similarity between the detection methods used by the storekeepers (Table 89).

Approximately one quarter of grain sites are not checked for insects whilst a similar proportion are checked using one or more types of static trap (pitfall, probe trap or baitbags). Half of the storekeepers use gravity spear or vacuum sampler to detect insects. Those sites using static traps were as likely to have the major grain pests present as those without traps.

Storekeepers were as diligent with regard to using the methods of insect detection in those sites where the major beetle pests were detected as they were where the pests were not found (Table 90).

Methods used by WSB Advisers to detect the grain beetle species

Table 91 illustrates the success of the various methods and traps used to detect *O. surinamensis*, *C. ferrugineus* and *S. granarius*. Probe traps and baitbags on the grain proved most effective for *O. surinamensis* whilst pitfall and probe combined were best for *C. ferrugineus* and *S. granarius*. When all species are combined it can be seen that there is an advantage in using both pitfall and probe traps for monitoring grain bulks. The combined use of pitfall and probe traps detected the major grain pests in three-quarters of the stores in which they occurred. It is interesting to note that, in those stores where the major pest species were found and where baitbags were placed on the structure of the building, the baitbags were successful in detecting the insects in one-third of the stores.

Fourteen storekeepers used pitfall and/or probe traps and yet did not detect the major species found by the advisers (Table 92). The frequency of use shows that the storekeepers were checking the traps at the correct interval, and that half of them were using the recommended combination of pitfall and probe traps. Table 93 shows that where the advisers used pitfall and probe traps in these stores they successfully trapped the pest species. This would indicate that although the traps were used in these stores, and checked at the correct interval, they were not functioning as intended. It is possible that the storekeepers were not positioning the traps correctly, not examining them thoroughly or were using traps which had lost the Fluon barrier and thus allowed captured insects to escape.

The comparative success of the static trapping methods used by the WSB Advisers is shown in Table 94, which gives details of those stores where all three methods (baitbags, pitfall and probe traps) were used on grain in which insects were found. It can be seen that the use of both pitfall and probe trap is necessary to enable detection of the 3 major pest species in grain. Baitbags, both on the grain and on the structure were equally valuable. Problems exist with any recommendation for the use of baitbags. Firstly, the baitbags may act as a source of infestation if not recovered from the grain and, secondly, they are attractive to rodents which can render them ineffective within a few days use.

The methods by which the minor grain beetle pest species were detected are shown in Table 95a. *Ahasverus advena* appears to be best detected by probe and pitfall as does *Typhaea stercorea*. *Ptinus* species were detected best by pitfall and baitbags. On grain (Table 95b), pitfall and probe traps were easily the most reliable detection method for the minor beetle pest species.

Summary

Three-quarters of all commercial grain store keepers use some method to detect insects in grain, and half of them are currently using sampling methods even though static trap methods are available. The use of static traps by WSB Advisers during a limited trapping period showed that pitfall and probe traps, when used together, will detect all the grain pest species. **However, when these static traps are used by storekeepers they do not appear to be providing the storekeepers with the early warning of the presence of the major grain store pests that would be expected from their use.**

Conclusions

i) Static traps should be used by all commercial grain storekeepers.

ii) Pitfall traps together with probe traps should be used in bulk grain, otherwise major pest species may go undetected.

iii) Attention to the correct use of the required number of static traps is needed within commercial grain storage.

iv) Storekeepers, including those already using static traps, should seek specialist advice on trap deployment and use.

CHAPTER 6

THE PSOCOPTERA FOUND IN THE COMMERCIAL GRAIN STORES

E C Spratt

Introduction

The status of psocids as a pest is debatable. However, they can, and do, damage grain and show a preference for attacking the germ. Damage is caused by the psocids eating a small hole in the seed coat covering the germ and then excavating the germ from the inside (Watt, 1965). Several individuals often invade one grain, and an apparently intact grain may, therefore, contain a hidden infestation. It is important that the storekeeper is aware of this potential problem and, in order to discover what species might be involved and how frequently they occur, samples of psocids were collected from the commercial grain stores.

Information on the psocid fauna of farm grain stores in England was provided by Spratt (1991) who found eight species of psocid in samples collected in 1987. In that survey the most commonly found species was *Lepinotus patruelis* which accounted for 82% of the psocid occurrences. Previous to that work the only other survey in Britain was by Broadhead (1954), and which covered grain stores, warehouses, silos, food depots, flour mills and ships' holds. This survey gave the frequency of occurrence of those species which were found in the first 100 samples from food storage buildings and the first 100 samples from ships. *L. patruelis* was found to be the most frequently occurring psocid in unheated buildings. The following chapter is intended to provide a more up to date and detailed account of the psocids found in commercial grain stores in England and Wales than has been available hitherto.

Methods

The psocids were collected from the bait bags, pitfall traps and probe traps which had been placed in the stores. They were separated from the other insects, and from the mites, before being sent to the Slough Laboratory for identification by the author.

Results

Psocids were collected from just over half of the sites. A total of seven species was obtained and details of the number of sites and stores where psocids were detected are given in Table 83. One of the species belonged to the family Trogiidae (suborder Trogiomorpha), four to the genus *Liposcelis* (suborder Troctomorpha) and two to the suborder Psocomorpha. All the species have a known association with buildings and four may also be found out of doors in Britain. Most samples were composed of only one species, but some contained up to five species.

The habits and habitats of psocids found in commercial grain stores.

Lepinotus patruelis is very common in places of food production and storage such as warehouses and grain stores in Britain. It has been associated particularly with cereal and dairy products (Freeman, 1977; Lilley, 1982). The common British name, the black domestic psocid (Seymour, 1989), which it shares with two other members of the genus, is inappropriate as it is neither black in its darkest form, nor is it especially associated with dwelling houses. It has also been called the black cereal psocid. 63 of the samples contained *L. patruelis* and they comprised 45.3% of the species records. Only in the two most southerly Regions did another species appear to be more common. *L. patruelis* is probably the most common insect in places of food production and storage in Britain despite its long developmental period and low productivity at low temperatures. The modified spermatophore produced by this species is likely to contribute considerably to its success.

The activity of *L. patruelis* adults in unheated premises when the temperature is unfavourable for many other arthropod species may provide phoretic mites with a means of dispersal. One sample of psocids collected from a commercial store was comprised of six *L. patruelis* males, all of which bore up to nine hypopi of *Acarus farris*.

It has been noted that the sex ratio in *L. patruelis* varies with the seasons (Fahy, 1971; Spratt, 1989). The numbers of males and females, collected during this exercise, and the sex ratios, are shown in Table 96 on a monthly basis . The males appear to be less cold hardy than the females.

Liposcelis bostrychophila, the stored product psocid, is thought to be the most common insect associated with customer complaints about insects in packaged food. This is a tropical species. The rate of increase is at its maximum around 30°C (Spieksma and Smits, 1975) and ceases below 17°C (Rassman and Wohlgemuth, 1984). However, it is tolerant of low temperatures (Spratt, unpublished). Therefore, when this species is present in unheated buildings numbers generally remain low and, in Britain, large populations are usually associated with heated premises. The potential rate of increase is very high in favourable conditions because the species is parthenogenetic, the developmental period can be short and the productivity high (Ghani and Sweetman, 1951; Rassman and Wholgemuth, 1984). Heavy infestations can cause damage to cereal grains, especially in the region of the germ (Watt, 1965; McFarlane, 1982), and weight loss in packaged, dried foodstuffs (Solomon, 1959).

Liposcelis entomophila was first described from specimens found infesting a museum insect collection. However, this is also a tropical species and occurs only occasionally in Britain and then, usually near to ports. The samples collected during this exercise were taken from a store near Bristol. *L. entomophila* is a common pest of foodstuffs, especially of rice and tea, in India, Malaysia and Indonesia (Srivastava and Sinha, 1975; Singh, 1972).

Liposcelis decolor has been found in leaf litter, caves, birds' nests, under bark and in buildings, and has been recorded from wheat and barley in store and at ports (Broadhead, 1954).

Liposcelis corrodens has the common name, the outhouse psocid. This species has also been recorded from grain in store and at ports. The Laboratory stock was obtained from bulk wheat. This species has also been taken from dwelling houses and deep-pit poultry houses (Anon., 1978).

Lachesilla pedicularia is commonly called the cosmopolitan grain psocid. Adults may be macropterous, but various degrees of wing reduction occur. Macropterous individuals may fly in swarms, especially in late summer and autumn. Such swarms sometimes enter buildings, but the presence of large numbers of brachypterous specimens in some grain stores indicates that the species may breed there. MAFF records indicate that *L. pedicularia* is more often associated with barley than with other cereals.

Ectopsocus briggsi is a macropterous species with occasional brachypterous specimens. It is widely distributed throughout the world, but is known to be more common in the south than in the north of England (New, 1971). The species is facultatively parthenogenetic and is the only species found in this exercise which lays its eggs in batches and covers them with webbing.

Discussion

Nearly all the commercial sites take in grain from farms and, therefore, it might be expected that the fauna of the commercial stores would reflect that found in farm stores by Spratt (1991). This does not appear to be the case. Three species of psocid, *Cerobasis guestfalica, Lepinotus reticulatus* and *Trogium pulsatorium*, found in the farm stores were not present in the commercial store samples, while two species, *Ectopsocus briggsi* and *Liposcelis entomophila*, were present in the commercial stores but not in the farm stores. An important factor in the distribution of psocids is the temperature. Some species overwinter in the egg stage (New, 1971) and the minimum temperature for the completion of the life cycle differs with the species (Rassman and Wohlgemuth, 1984; Spratt, 1989). The farm store exercise was conducted during the summer when the grain stores were largely depleted of grain and the only method of collecting psocids was by using bait bags. In contrast the commercial store exercise took place in the autumn and winter, and at a time when the grain stores contained large amounts of grain. In addition the samples from the commercial stores were collected from probe and pitfall traps, as well as from bait bags. It is possible that these differences in season, in the amount of grain in store and in the sampling method, may have contributed to the observed differences in the psocid fauna. This exercise, and the one concerning farm stores, has shown that psocids are very common in grain stores, and that in Britain the two most commonly found species are *L. patruelis* and *L. pedicularia*.

Summary

(i) Psocids were found at 65% of the sites and in 55% of the stores.

(ii) The great majority of detections were from the grain in store.

(iii) The most commonly found species were *Lepinotus patruelis* and *Lachesilla pedicularia*.

Note on nomenclature The genus *Liposcelis* has recently been revised by Lienhard (1990). The synonyms of the species found in this exercise are:

L. entomophila	=	*L. entomophilus*
L. bostrychophila	=	*L. bostrychophilus*
L. decolor	=	*L. terricolis*
L. corrodens	=	*L. subfuscus*

CHAPTER 7

THE DISTRIBUTION OF MITES IN COMMERCIAL GRAIN STORES

S M Lynch, J Muggleton and J C Starzewski

Introduction

There does not appear to have been any previous published investigation of the mites found in commercial grain stores in the UK. The assumption has been that the mite fauna of such stores would mirror that of the farm grain stores, from where much of the grain will have been derived. We now know, however, that the mite fauna of farm grain stores is by no means constant. A comparison of the 1973 post-harvest survey of farm grain stores (Griffiths, Wilkin, Southgate and Lynch, 1976) with the 1987 pre-harvest Information Gathering Exercise (Lynch and Muggleton, 1991) suggests that while *Glycyphagus destructor* is the commonest mite when the stores contain grain after the harvest, *Acarus siro* is the commonest species in the largely empty stores before the harvest. The conclusion drawn (Lynch et al., 1991) was that the mite fauna of the grain post-harvest reflects the many field species that will have come into the store with the newly harvested grain, whereas in the empty grain stores it is the specialist grain store mite, *Acarus siro*, that is predominant.

Methods

The methodology for the collection of mites is detailed in the inspection protocol (Appendix 3). All methods of trapping were employed to find mites. Once collected the mites were separated from the insects and any debris present in the traps and placed in the tubes provided for transit to the Slough Laboratory. The tubes contained a small amount of mite food, and a filter paper wick which was to be moistened before the tubes were dispatched. Following the failure of many samples of mites to survive the journey to the Slough Laboratory during the 1987 Information Gathering Exercise, the instructions were re-worded to stress the need to avoid excess moisture in the tubes and for their prompt dispatch. These points were also emphasised during the Advisers' briefing. As a result the loss rate was much reduced from that experienced in the previous exercise.

On arrival at Slough the mites were removed from the tubes and examined under a low power microscope at magnifications of between x7 and x30; this enabled the mites to be identified to genus. Slides of the mites were then made for their identification to species level. The number of mites used for the production of the slides depended on the numbers within the sample. If the number available was very low, or only nymphal stages were in evidence, the production of the slides was delayed until the numbers had increased or the mites had matured in culture. Generally five adults of each genus were picked out using either a single hair brush or a fine mounting needle. The mites from each genus were mounted on separate slides in "Heinz" medium (30-36 PVA) under 13 mm cover glasses on standard glass microscope slides. Each slide was carefully labelled before being 'fixed' in a slide oven for at least 24 hours.

Results

Mites were recorded from 137 sites and from 230 stores, and samples from 125 of the sites and 207 of the stores were successfully identified. The number of sites and stores at which each of the genera *Acarus*, *Glycyphagus* and *Tyrophagus* were found is given in Table 84. The species identifications are given in Table 85; three species of *Acarus* and *Tyrophagus*, and two species of *Glycyphagus* were found. Table 84 also shows the various combinations of the mite genera found at the sites and stores, and Table 97 shows the combinations of species, within each genera, found in the stores.

Discussion

At both sites and stores *A. siro* was the mite most frequently found, with *G. destructor* occurring almost as frequently. *T. longior* was the next most common species with *T. putrescentiae* the fourth most common. The frequency of species differs, therefore, from both farm surveys in which there was a preponderance of either *G. destructor* or *A. siro* (see Table 98). *T. longior* was the third most common species in all the surveys, but the position of *T. putrescentiae* and *T. palmarum* is reversed comparing this exercise with that of 1987. *G. domesticus* and *A. farris* were very infrequent in the commercial stores, in contrast to their rather higher frequency of occurrence in the farm stores. Two species of *Glycyphagus* and two species of *Tyrophagus* which were found in the farm stores were not found in the commercial stores.

Two or more genera were present at 62.8% of the commercial stores, compared with 47.4% of the farm stores inspected during the 1987 Information Gathering Exercise and 73.1% of the stores in the 1973 survey (see Table 99). Within the genera there is perhaps a greater tendency for only a single species to be present in the commercial stores.

Comparing the commercial store fauna with that found during the two farm surveys, the picture is one of fewer species present in the commercial stores. This is probably accounted for by the fact that, in general, the commercial stores are one step further away from the growing crop and the farm environment than the farm stores, and therefore some field species, such as *T. palmarum* and *G. domesticus*, are less common while others, such as *G. ornatus*, *G. michaeli*, *T. similis* and *T.* sp. nov. are not found at all. It is also probable that the physical removal of the grain from one store, or place, to another will kill many of the mites. It is interesting to find that *A. siro* and *G. destructor* are almost as equally common as each other in the commercial stores, whereas the expectation might have been that *G. destructor* would be the more frequently found species. Again it is possible that the removal of the grain to the commercial store has led to a reduction in the frequency of *G. destructor* in the grain, and it is not, perhaps, surprising that *A. siro*, the grain store specialist, should be so frequent.

From Table 84 it can be seen that the proportion of *Acarus* : *Glycyphagus* : *Tyrophagus* is constant in the stores from Region to Region ($G = 4.268$, 25 d.f., ns). There is, therefore, no evidence of any geographical trends in the distribution of the genera. The same is true when comparing the Regional distribution of the different species of *Acarus* and *Glycyphagus*, but in *Tyrophagus* the proportion of *T. longior* in the Eastern Region is double that of *T. putrescentiae*, whereas elsewhere the two species occur with equal frequency. This difference is not, however, significant ($G = 2.343$, 1 df, ns).

Storage practice and, in particular, the use of insecticides might be expected to have an effect on the number of stores with mites present, especially as the most frequently used insecticide, pirimiphos-methyl, is also recommended as a grain store acaricide. Table 100 shows the number of occurrences of the three genera in stores where all, or part, of the fabric was treated in the previous twelve months compared with those where there was no treatment, and in stores where all or part of the grain was treated in the previous twelve months compared with those where it was not treated. The comparisons of the fabric treatment appear to show that *Acarus* and *Tyrophagus* occur more frequently in the stores where the fabric has been treated than in those where it has not been treated, whereas for *Glycyphagus* there is no difference. These data need to be treated with some caution. It is possible, for example, that the fabric was treated because mites were present and that the treatment was effective in reducing the number of mites even if it did not completely eliminate them. In this regard it is important to remember that what was recorded was the occurrence of a species, not the numbers present, and so it would be possible, but highly unlikely, for a single mite to be detected and recorded as an occurrence. A comparison of the grain treated and not treated apparently shows no difference in occurrence for *Acarus* and *Tyrophagus*, but significantly more occurrences of *Glycyphagus* on the untreated, compared to the treated, grain. Again caution needs to be exercised when interpreting these data. It may, however, be a cause for concern that the occurrences of *Acarus* and *Tyrophagus* are significantly different from those of *Glycyphagus*, in relation to insecticide treatment, for it is these two genera which show the highest frequencies of pirimiphos-methyl resistance (see Table 117), whereas the frequency of pirimiphos-methyl resistance in *Glycyphagus* is much lower. We cannot, therefore, discount the possibility that some *Acarus* and *Tyrophagus* may be surviving the insecticide treatments applied at some stores.

<u>Summary</u>

(i) Mites were found in over 80% of stores.

(ii) Three species of *Acarus* and *Tyrophagus*, and two species of *Glycyphagus* were found.

(iii) The most frequently found species were *Acarus siro* and *Glycyphagus destructor*, which both occurred in just over half the stores.

(iv) There was no evidence of any geographical trends in the distribution of the three genera, *Acarus*, *Glycyphagus* and *Tyrophagus*.

(v) *Glycyphagus* were more likely to be found in untreated rather than treated grain.

(vi) *Acarus* and *Tyrophagus* were found as frequently in treated as in untreated grain.

CHAPTER 8

INSECTICIDE AND FUMIGANT RESISTANCE - COMMERCIAL GRAIN STORES

J Muggleton, J A Llewellin, A L Clifton and A J Prickett

Introduction

Resistance in stored product beetles has been recognised since the early 1970s when a worldwide FAO survey investigated the resistance of eight species of stored product beetles to malathion, lindane and the fumigants methyl bromide and phosphine (Champ and Dyte, 1976). In Great Britain, malathion resistance was found to be present in *Rhyzopertha dominica, Sitophilus oryzae, S. granarius, Tribolium castaneum and T.* confusum but absent in *Oryzaephilus mercator, O. surinamensis* and *S. zeamais*. Lindane resistance was found in all eight species. Methyl bromide resistance was found in *O. surinamensis, T. castaneum* and *T. confusum*, and phosphine resistance was found in *T. castaneum, T. confusum* and the three *Sitophilus* species. Subsequently resistance to the organophosphorus insecticides appears to have increased. Data for the years after the FAO survey (Muggleton, 1987) show that the frequency of malathion resistance increased in the decade following the early 1970s but remained at or about the 1979-1982 level for the period 1983-86. Data for 1984-86 showed that for *O. surinamensis* nearly 30% of the populations tested were resistant to pirimiphos-methyl and malathion, a small proportion (6%) were resistant to fenitrothion, but that nearly all (92%) were resistant to chlorpyrifos-methyl.

The disadvantages of these earlier data are that they are not a random sample, coming from premises with infestation problems and thus where resistance is more likely to be found, and that for most species it was possible to test only for malathion resistance. For the 1987 Information Gathering Exercise on farm grain stores (Muggleton and Prickett, 1991) the first of these disadvantages was overcome by using a random sample of farms, while the development of more discriminating dose tests enabled both *O. surinamensis* and *Cryptolestes ferrugineus* to be subjected to resistance tests for a range of organophosphorus compounds. The results of the resistance tests on *O. surinamensis* from the farm grain stores were in broad agreement with the 1984-86 data, except that the proportion resistant to malathion had dropped to 13%. Data for methacrifos and etrimfos resistance were available for the first time and showed that methacrifos resistance was present in 77% of the samples, and etrimfos resistance was present in 18% of the samples. For the first time resistance could be detected to four organophosphorus compounds, in addition to malathion, in *C. ferrugineus*, but only 5% proved resistant to etrimfos and 9% to malathion. In the current exercise the earlier problems of sampling have been overcome by attempting to collect samples from all those sites storing grain commercially, while two further discriminating dose tests, to chlorpyrifos-methyl in *S. granarius* and *S. oryzae*, have been added to those previously available.

Resistance - a definition

For the purposes of this work, resistance has been defined as occurring where insects have inherited the ability to survive a discriminating dose of insecticide designed to kill all normal or susceptible insects in a population. Resistance has therefore been defined as a result of laboratory tests, and these should not be taken to imply that the beetles would necessarily survive a correctly applied field treatment.

Methods

(a) Insecticide resistance

Adult beetles were exposed to discriminating doses of insecticide following the general procedures set out in FAO Method No. 15 (Anon., 1974), in which beetles are confined on insecticide treated filter papers by glass rings coated with "Fluon" (an aqueous suspension of polytetrafluoroethylene). With the exception of methacrifos, the doses of insecticide were applied to Whatman No. 1 filter papers in a mixture of Shell "Risella" oil, petroleum ether and acetone in a ratio of 1:3:1 by volume. 0.5 ml of this mixture was applied to each filter paper which was then left to dry for 18 hours. Methacrifos was applied in a mixture of polyethylene glycol (molecular weight 300) and acetone in a ratio of 1:4 by volume. Technical grade malathion (89.5% pure), fenitrothion (95.9% pure), chlorpyrifos-methyl (86.3% pure), pirimiphos-methyl (90.8% pure), methacrifos (95.1% pure) and etrimfos (67% pure) were used throughout. The discriminating doses used to detect resistance are shown in Table 101.

(b) Fumigant resistance

Adult beetles were exposed to methyl bromide and phosphine following FAO Method No. 16 (Anon., 1975). The method involves the exposure of batches of around 100 four week old adults to a discriminating dose of the fumigant. The exposure is carried out at 25°C and 70% RH in gas-tight glass desiccators of known volume. The exposure period for methyl bromide was 5 hours, and that for phosphine was 20 hours. At the end of the exposure period the beetles were removed, placed on food in 120 ml glass jars and then left at 25° and 70% RH for two weeks, at which time an assessment of mortality was made. For each test two replicates of 50 beetles of each strain were used, and a further two replicates of 50 beetles were placed in non-treated desiccators to act as controls. The discriminating doses used to detect resistance are shown in Table 102.

Results

Tables 103, 104, and 105 show the results of all the resistance tests carried out on *O. surinamensis, C. ferrugineus, S. granarius* and *S. oryzae*. The results are presented as percentage beetles knocked-down; at least 100 beetles were tested against each compound. Those stores where insecticide was used on the grain or in the grain store in the previous year are marked by an asterisk (*), and those stores where a fumigant treatment had been carried out are marked by a cross (+). In Figure 3 the results for *O. surinamensis* are presented as histograms in order to display more readily the proportion of strains that had high and low knockdown values. Tables 106, 107 and 108 show the results summarised for each MAFF Region and Wales.

From the summary tables it will be seen that in most instances the number of stores where a species was detected is greater than the number of stores for which resistance tests were done. This shortfall was for one of three reasons, either the beetles were not sent to the Laboratory, or they were dead on arrival, or they failed to breed-up. Adults not being sent to the Laboratory would seem to be the most common reason for the shortfall.

For *O. surinamensis* it is possible to tabulate the various combinations of resistance found amongst the 27 strains tested. This tabulation is shown in Table 109. For ease of comparison, combinations of resistance that were found in the farm store populations (Muggleton *et al*, 1990) but not here, are also included. There are too few data for *C. ferrugineus* and *S. granarius* to make similar tabulations of resistance combinations for these species.

Discussion

These results, like those from the farm store exercise, show that resistance to organophosphorus insecticides is limited in *C. ferrugineus* and *S. granarius*, but widespread in *O. surinamensis*. There are, however, some striking differences between the resistances found in *O. surinamensis* from farm and commercial grain stores (see Table 110). Resistance was more frequently detected in the commercial store *O. surinamensis* populations than in those from the farm stores. The notable exception to this being methacrifos resistance which was much less frequent in the commercial stores than in the farm stores. As with the farm stores it is particularly interesting to see resistance to compounds that are used infrequently (see Table 72) such as, etrimfos, methacrifos, malathion and fenitrothion, although resistance to the latter two compounds may still be present as a result of their past use in grain stores.

The higher frequency of detection of resistance at the commercial stores compared with the farm stores probably has two causes, the more extensive use of insecticides in commercial stores and the concentration in the commercial stores of "packets" of grain from many different sources. The lower detection of methacrifos resistance in the commercial stores is puzzling and goes against the general rule of increased occurrence of organophosphate resistance. This would seem to suggest that methacrifos resistance can be inherited separately from resistances to other organophosphorus compounds. Strangely in the one strain in which there has been a detailed laboratory examination of the inheritance of organophosphorus resistance, it was found that chlorpyrifos-methyl and methacrifos resistance were inherited together, but separately from that for the other organophosphorus compounds. There is a possibility, of course, that methacrifos resistance has been mis-scored in one or other of the exercises. To test this hypothesis, six methacrifos resistant strains that had been retained from the farm store exercise were re-tested using the same operator and methacrifos solution as for the commercial store tests. All were still found to be resistant to methacrifos, and thus mis-scoring seems unlikely. Examination of the results of all the discriminating dose tests suggests that there is no relationship between methacrifos resistance and that to any other compound. Nor is there a relationship between resistance to chlorpyrifos-methyl and that to any other compound. There is, however, a significant correlation between knockdown to pirimiphos-methyl and that to etrimfos ($r = 0.796$, $n = 27$, $P < 0.01$), and although the number of resistant strains is small there would also seem to be a relationship between malathion and fenitrothion resistance. Of particular interest are the five strains (5009/1, 6018/1, 7002/1, 7012/1 and 7014/1) which show combined resistance to malathion, fenitrothion, pirimiphos-methyl and etrimfos. These strains show a strong positive relationship between knockdown values for each compound; this can be seen in Table 111 where the strains are listed in order of their increasing susceptibility to malathion. This suggests that in these strains there is true cross-resistance between these four compounds and that resistance to methacrifos, and probably also to chlorpyrifos-methyl, is controlled separately. These strains would therefore appear to be similar to the multi-organophosphorus resistant strain (01090) collected in England in 1981 (Muggleton, 1987) and may be expected to be resistant to a wide range of other unrelated insecticides. The farm store exercise produced only one strain with this spectrum of multi-organophosphorus resistance. If these three strains are removed from the correlation analysis of the pirimiphos-methyl and etrimfos knockdown values, the correlation becomes non-significant ($r = 0.197$, $n = 22$), suggesting that for the remaining 22 strains there is no cross-resistance between pirimiphos-methyl and etrimfos. A tentative conclusion on the basis of these results suggests that there are mechanisms giving specific resistances to malathion, chlorpyrifos-methyl, pirimiphos-methyl, methacrifos and etrimfos and a further mechanism giving cross-resistance between malathion, fenitrothion, pirimiphos-methyl and etrimfos. One or more of these mechanisms may be found in one strain, giving a wide range of possible multiple resistance patterns. This conclusion needs to be verified by laboratory studies on cross-resistance.

It might be expected that the presence of resistant beetles would be related to pesticide usage at the commerial stores from which they were collected. However, there is no significant difference between pesticide usage in those stores with resistant strains of *O. surinamensis* as compared to the usage in all the stores ($chi^2 = 1.083$). Table 112 shows the percentage of stores in each category. Looking at specific compounds, of the 22 stores with pirimiphos-methyl resistant *O. surinamensis*, 16 had used pirimiphos-methyl. Of the five stores with pirimiphos-methyl susceptible *O. surinamensis*, three had used pirimiphos-methyl. Of the eight stores with methacrifos resistant *O. surinamensis*, only one had used the compound; none of the stores with methacrifos susceptible *O. surinamensis* had used the compound. Of the five stores with fenitrothion resistant *O. surinamensis*, one had used the compound; none of the stores with fenitrothion susceptible *O. surinamensis* had used the compound. Only seven of the 27 stores with chlorpyrifos-methyl resistant *O. surinamensis* had used chlorpyrifos-methyl, and only 3 of the 27 stores with etrimfos resistant *O. surinamensis* had used etrimfos. Thus there is no evidence from this data of a relationship between the resistance found in *O. surinamensis* and the insecticides used in the stores in the previous twelve months. An examination of the data from the farm store information gathering exercise (Muggleton *et al* 1991) gives the same finding. This does not mean that such a relationship does not exist. Various difficulties arise when comparing the resistance found with insecticide usage. In our questions, for example, no account was taken of pesticide usage more than twelve months previously, and past use of insecticide could, of course, determine resistance levels in an endemic pest population. Nor has any account been taken of any pesticide usage the beetles might have experienced before arriving in a particular store. If we assume that at any one time the grain in store is likely to have come from a number of sources, than any pests coming with it would tend to reflect pesticide usage at their point of origin. In this respect it seems probable that the greater frequency of pesticide resistance found in the commercial stores, compared with the farm stores, reflects the bringing together of strains of beetles from diverse sources just as much as it reflects the more frequent use of pesticides in the commercial stores. However, taking the farm and commercial stores together, it is evident that pirimiphos-methyl is the most widely used insecticide, with chlorpyrifos-methyl in second place, and the other insecticides being used infrequently. It might be supposed, therefore, that there would be more strains resistant to pirimiphos-methyl than to the other compounds, and that those strains would generally show lower frequencies of knockdown to pirimiphos-methyl than to the other compounds. From Table 103 we can see that the former supposition is not true, and looking at Figure 3 we can see that neither is the latter supposition true.

Most pirimiphos-methyl resistant strains of *O. surinamensis* have high knockdown values whereas for etrimfos there is a wide scatter of knockdown values, and the values for chlorpyrifos-methyl fall somewhere in between. So again, in *O. surinamensis* the expected correlations between insecticide usage and insecticide resistance are not present. For *C. ferrugineus* and *S. granarius* there are too few data to draw any conclusions. Widespread insecticide usage coupled with extensive cross-resistance would explain these results, but as we have seen the data suggest that true cross-resistance is not frequently found.

It remains, therefore, unclear why current field populations of *O. surinamensis* should display this wide range of resistances and what the selective agent is that has brought these resistances about. A study of six grain stores in Minnesota has shown the existence in *O. surinamensis* of chlorpyrifos-methyl resistance with low knockdown frequencies at four stores in the absence of chlorpyrifos-methyl usage (Subramanyan, Harein and Cutkomp, 1989). This, together with the widespread existence of chlorpyrifos-methyl resistance in the UK, points to the possibility that some individuals of *O. surinamensis* have a natural tolerance of chlorpyrifos-methyl. This has presumably arisen as a result of the need to detoxify some naturally occurring compound in the species' environment, the same detoxification pathway also acting on chlorpyrifos-methyl. Perhaps other such mechanisms exist in *O. surinamensis*, but not in the other species we have dealt with here.

<u>Summary</u>

(i) There is evidence of widespread resistance in *O. surinamensis* to all currently available organophosphorus insecticides.

(ii) Resistance to organophosphorus insecticides in *C. ferrugineus* and *S. granarius* is infrequent.

(iii) There is little evidence of resistance to fumigants.

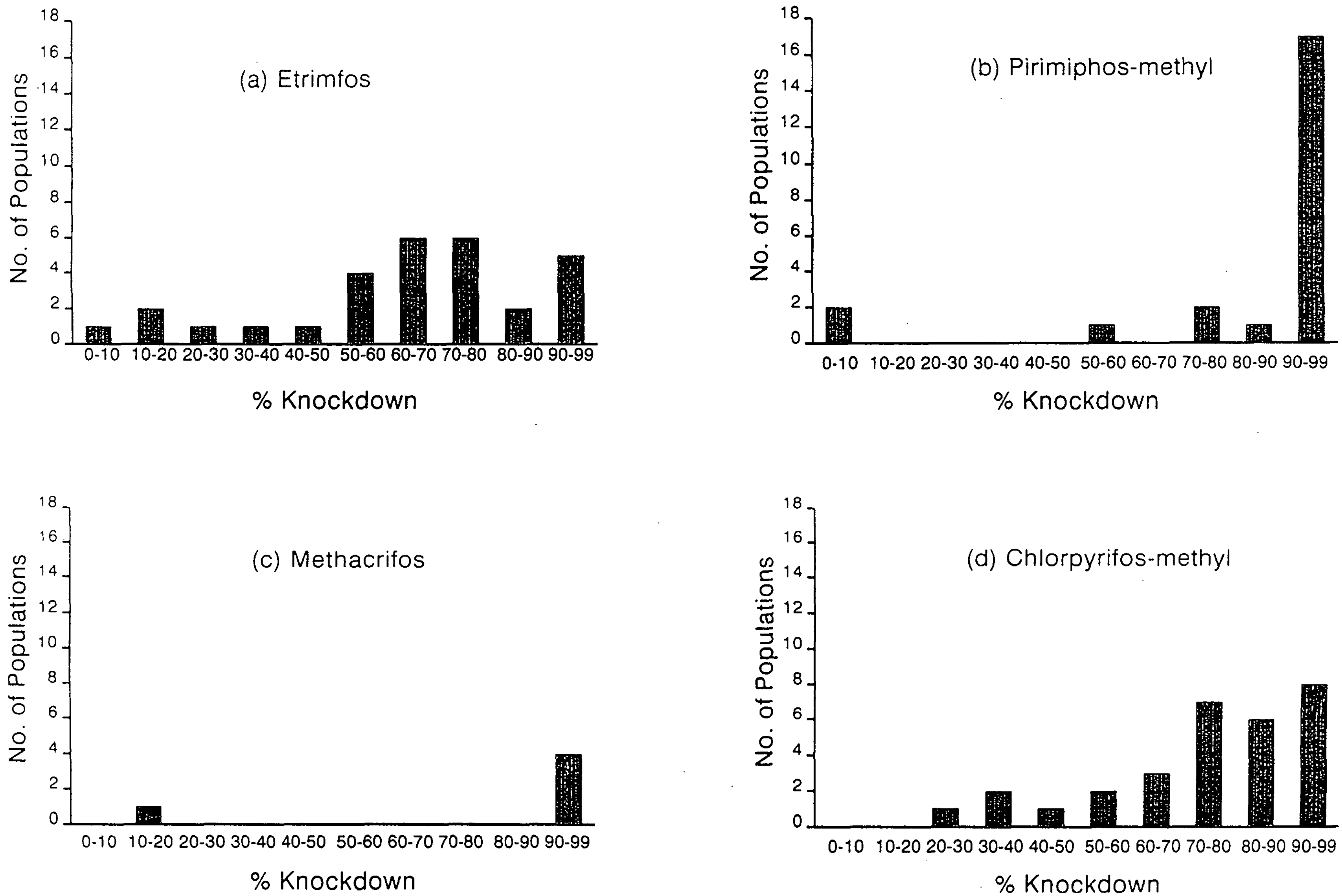
(iv) The resistance in *O. surinamensis* appears to be complex and must involve several mechanisms.

(v) Although not necessarily leading to control failure, the resistances found would make the insects more difficult to control, and may reduce the effective life of residual treatments.

(vi) There is no evidence that current insecticide usage in commercial stores is related to the resistances found.

(vii) The origins of the resistances and the reasons for the differences between the species remain unclear and require further investigation.

Figure 3. The distribution of knockdown values for the 28 *O. surinamensis* populations tested for resistance to pirimiphos-methyl, etrimfos, methacrifos and chlorpyrifos-methyl.



CHAPTER 9

THE INCIDENCE OF RESISTANCE TO PIRIMIPHOS-METHYL IN STORED PRODUCT MITES COLLECTED FROM COMMERCIAL GRAIN STORES IN THE UNITED KINGDOM

J C Starzewski

Introduction

Pirimiphos-methyl was given full clearance for use on stored commodities in 1973. It has broad spectrum insecticidal activity and good acaricidal properties (Wilkin & Hope, 1973 ; McCallum-Deighton & Pascoe, 1976). Since its introduction it has become the most widely used organophosphorus pesticide in storage practice. This was confirmed by both the farm grain store information gathering exercise (Prickett, 1988) and by the present exercise (See Table 37).

Resistance to pirimiphos-methyl in mites in the UK was first reported in 1979 in *Acarus farris* and *A. chaetoxysilos* populations collected from cheese stores in Dorset (Stables & Wilkin, 1981). Later resistance was reported in populations of *Tyrophagus palmarum* and *T. putrescentiae* (Stables, 1984) from cheese stores. Stables (1984) was able to state that, 'no resistance to pirimiphos-methyl has so far been detected by regular collection and monitoring outside cheese stores'. This remained the situation until the 1987 farm grain store Information Gathering Exercise showed that pirimiphos-methyl resistant populations of mites occurred on 16% of farms in England, with resistant populations of *A. siro* and *T. longior* being recorded for the first time in the UK (Binns and Starzewski, 1991).

Methods

Single genus cultures were set up at the Slough Laboratory from mites collected at the stores. Whenever possible at least 50 individuals were used, and these were placed in 25ml or 50ml conical flasks stoppered with non-absorbent cotton wool. The culture medium consisted of a heat sterilized mixture of debittered yeast and pesticide-free ground wheatgerm in a ratio of 3:1 by weight, which was conditioned at 80% RH for at least 48 hrs (Solomon & Cunnington, 1964). All the cultures were maintained over potassium hydroxide solutions in plastic desiccators at 80% RH and at 17.5°C. The time required to breed up the cultures to a sufficient size for testing varied between 2 and 6 weeks, depending on the initial numbers and condition of the mites.

Resistance testing was based on the method described by Wilkin & Hope (1972), and used pirimiphos-methyl emulsifiable concentrate ("Actellic", 25% a.i, ICI). Mites were tested for resistance at a discriminating dose of 8mg/kg of pirimiphos-methyl applied to wheat (Stables & Wilkin, 1981). Pesticide-free English wheat with a moisture content of 16%, as determined by British Standard method BS 411, was used as the substrate. The diluted pesticide was applied at a rate of 10ml/kg using a "DeVilbis" spray gun at an application pressure of $0.35kg/cm^2$ ($5lb/in^2$). Approximately 0.01g of vigorous mite culture was added to three 25g replicates of treated wheat and to three 25g replicates of untreated wheat contained in 100ml glass jars. Three known susceptible cultures which have been kept in pesticide free conditions for a number of years were also set up during each test as controls. These control cultures were of *A. siro*, *G. destructor* and *T. longior*, which were taken to be representative species of the three genera. As an additional control three replicates of untreated grain to which mites had not been added were set up to ensure that the grain had been properly disinfested before use. An assessment of each jar of grain was carried out after 14 days. A culture was considered resistant if more than 2 live adult mites were detected in each treated replicate. After testing a representative number of survivors were used to produce slides for identification to species.

Results

Samples of mites were received from a total of 133 (85%) of the 157 commercial grain storage sites inspected in the five ADAS Regions and Wales. On each site up to 4 discrete storage structures were examined and this resulted in the collection of mites from 225 (80%) of the 283 stores inspected.

Eight species of mites from three genera were identified from slides made on first receipt of the material. The three most commonly occurring species were *A. siro*, *G. destructor* and *T. longior*. Sorting of the samples resulted in 289 single genus cultures being set up (155 *Acarus* spp., 92 *Glycyphagus* spp. and 42 *Tyrophagus* spp.), and tested, from 119 (90%) of the 133 sites from which mites were received. The results of the resistance tests are shown in Tables 113, 114 and 115. The tests revealed that resistant mites were present at 85 of the 119 sites, and in 122 of the 192 stores, from which mites were tested. Resistance was restricted to three species, *A. siro*, *G. destructor* and *T. putrescentiae*. Table 116 shows the various combinations of resistant species found at the sites.

Discussion

The present exercise has shown resistant mites to be present at 71.4% of the sites, and 63.5% of the stores, from which mites were tested. Thus resistance in the commercial grain stores appears to be much more widespread than in farm grain stores of which only 16% were found to have resistant mites (Binns and Starzewski, 1991). Although eight species were detected during this exercise, an examination of the slides produced from the mites surviving treatment showed that resistance was confined to three species, *A. siro, T. putrescentiae* and *G. destructor*. This is the first occasion on which pirimiphos-methyl resistant strains of *G. destructor* have been found in the UK. Table 115 shows that resistance is most frequent in *T. putrescentiae* where all the strains tested were resistant to pirimiphos-methyl, and least frequent in *G. destructor* where 10.9% of the strains tested were resistant. The pattern of resistance among the species is therefore very different from that found during the 1987 farm grain store exercise, in which resistance was found most frequently in *A. siro* and where there was no evidence of resistance in *T. putrescentiae*, although resistance was found in the other *Tyrophagus* species. These differences are difficult to explain. The greater frequency of *T. putrescentiae* in the commercial stores, and hence its greater exposure to insecticides than in the farm stores, might explain the difference in frequency of resistance in this species, but does not explain the absence of resistance in *T. longior*.

From Table 116 it can be seen that, where resistance is present, in the majority of cases it is restricted to one species. However, at a third of the sites with resistant mites the resistance extends to two or three species. These data contrast with the findings of the farm store exercise, where resistance was confined to a single species in those farm stores where it was detected. Looking at the distribution of resistance between stores and regions, there is no significant difference in the frequency of stores with resistant mites between the MAFF Regions ($chi^2 = 7.85$, ns); Wales has been excluded from the comparison because the number of stores from which mites were tested is too small.

The discriminating dose of 8mg/kg used to treat the grain is twice the dose which is approved for field treatment. The possibility arises, therefore, that populations which did not survive the laboratory discriminating dose might be able to survive the lower field dose, and thus these results may underestimate the control problem. It must be admitted that the majority of sites inspected possessed resistant populations of mites and that there was little evidence of the use of insecticide treatments affecting mite occurrence in the stores (see Chapter 7). Fortunately the control of mite pests is not solely dependent on chemical means; good hygiene procedures and, more importantly, the careful control of physical conditions within stores (ie temperature and relative humidity) will prevent the development of infestations. It is worrying, however, to find such widespread resistance to this compound in an increasing number of species for two reasons. Firstly the data suggest that this compound may be losing its effectiveness as a means of controlling storage mites and secondly there is the possibility that cross-resistance may arise to other alternative organophosphorus compounds. This has already been demonstrated between pirimiphos-methyl and the organophosphorus compounds chlorpyrifos-methyl, etrimfos and methacrifos in one species of storage mite (Stables & Wilkin, 1981). Should this occur it might eventually result in the loss of these compounds as a means of controlling mite infestations.

<u>Summary</u>

(i) All *T. putrescentiae* populations tested, and 71% of *A. siro* populations tested, were found to be resistant to pirimiphos-methyl.

(ii) 89% of *G. destructor* populations tested were found to be susceptible to pirimiphos-methyl.

(iii) The ability of the resistant populations to survive a dose twice that recommended for treatment in the field would be sufficient to cause control problems.

CHAPTER 10

SUMMARY AND CONCLUSIONS

Site Visits

This exercise has provided an objective and quantified picture of the commercial grain storage industry, which is of value both in demonstrating the efforts of the industry to maintain the quality of the grain, and as a bench-mark against which any changes in storage practice over time can be measured.

The total storage capacity of commercial stores in England and Wales was estimated to be 4.5M tonnes, at 179 sites, with nearly half occurring in the MAFF Eastern Region. This capacity comprised 83% floor-storage, 4% internal bin storage and 13% external bin or silo storage. Just over half (57%) of the floor-stores were purpose-built structures, accounting for 41% of floor-storage capacity, with the rest being almost evenly split between converted hangars and other buildings.

Sites were generally well equipped with grain cleaning, drying and cooling facilities, which were present at 62.2, 67.5, and 91.8% of sites respectively: they had been used at 59.2, 65.7 and 90.6% of sites during the twelve month period. It is not possible to judge from the data whether the absence of a facility was because it was not needed, nor whether the site could benefit from installing it. Only five sites (3.0%) had none of these facilities and, of these, three were associated with ports and concerned primarily with exports.

Except for four sites that had refrigeration equipment, all sites that had cooled grain had done so using ambient air. Automatic fan controls - either thermostats or timers - were installed at 28.8% of these sites but about half of these also exercised manual control, so that 84.3% of sites relied partially or totally on staff to switch the fans on or off.

Research by the MAFF Central Science Laboratory, funded by the Home-Grown Cereals Authority, has shown that the use of differential thermostats to control ambient air cooling systems can lead to a substantial reduction in running costs. This method is effective during the autumn and winter months, and typically the thermostat would be set to operate when the ambient air was 2-4°C cooler than the grain. Differential thermostats were present at only three sites, so there is scope for reducing running costs at the majority of sites.

Action to avoid the introduction of insects to stores was almost universal, with 91.6% of sites reporting that they checked grain for infestation on intake and 89.8% operated a nil tolerance for the presence of insects, although most would not reject grain on the basis of small numbers of mites. Just over half (59.3%) of sites had rejected grain during the twelve months because pests were detected.

With few exceptions, intake grain was sampled by spear or vacuum and both methods were equally common. Whilst these are accepted methods, and can often be successful in detecting the presence of insects, they rely necessarily upon the examination of a small fraction of the grain and consequently are unlikely to detect insects when they are present in small numbers. Equally, these small numbers are unlikely to be detectable if the grain is soon sold.

Grain in store was monitored for the presence of pests at all but 5.9% of the sites, with 86.5% using grain sampling and/or insect trapping methods. The remaining few sites relied on visual examination or limited sieving.

Grain sampling can detect insects and mites only if they are present within the sample taken and therefore its success depends upon the intensity of sampling, both in time and space. Insect trapping methods are generally more effective than grain sampling, except perhaps at very low temperatures when the insects are inactive. Pitfall traps detect insects moving across the surface of the grain, probe traps detect those in the grain, and bait bags can be placed on or in the grain and on the structure of the store. These traps differ in their effectiveness depending upon the species of insect and thus should ideally be used in combination. Although 38.2% of sites used insect traps, only 18.8% used them in combination, suggesting that many sites would benefit if the advantages of this method, and the best deployment of traps, were more widely known. Storekeepers, including those already using static traps, should seek specialist advice on trap deployment and use.

As well as inspecting the grain on intake, most (85.8%) sites reduced the likelihood of pests entering the grain by treating the fabric of the store with insecticide. Two-thirds (67.5%) of sites treated some or all of the grain with protectants, but it was estimated that overall only 23.0% of the grain that was present, or that had passed through during the twelve months, had been treated on site, the other 77.0% was not treated during its storage in the commercial stores.

Given the cosmopolitan distribution of rats and mice, it is not surprising that rodent control was carried out at very nearly all the sites, with rodenticides used at 97.7%. Birds appeared to be seen as less of a problem, with 32.9% of sites exercising control, and half of these involved proofing the structure against bird entry.

Store Inspections

A single live insect or mite was sufficient for that species to be recorded as present. Thus their presence should not be taken to imply there was an infestation, rather that there was a direct threat to the grain which might develop into a problem if no remedial action was taken. At each store the manager was informed of the results of the inspection.

None of the major beetle pests of grain, *Oryzaephilus surinamensis*, *Cryptolestes ferrugineus*, and *Sitophilus* spp, were detected in three-quarters (73.5%) of the stores inspected. In the 26.5% of stores (39.5% of sites) where these beetles were found, each occurred with a similar frequency - 14.3, 10.6 and 13.1% of all stores respectively. Although this frequency suggests that they pose an equal threat to grain, store managers most often specified *Oryzaephilus* as the most significant potential pest. The three beetles were detected mostly in the grain (22.3% of stores) and were found in or on the structure in 7.4% of the stores.

Cooling the grain to a temperature at which pests cannot develop, and treatment with a grain protectant, are two methods which obviously have a considerable effect upon the likelihood of insects being present in the grain. However, with one exception, analysis of the data showed no significant difference in the frequency of the major beetle pests between stores that did and those that did not use either of these methods. The exception was that *O. surinamensis* was less often detected in cooled than un-cooled grain. It may be that a difference did exist but the sample sizes were too small to demonstrate it. Conversely, it may be that these control methods were not exercised where there was no perceived threat, while their use reduced the frequency to this level, resulting in few insects which were nevertheless detectable during the survey. This would suggest that more effective monitoring of the grain is needed in at least some of the stores, which should lead to a further reduction in the occurrence of these beetles.

Minor, or secondary, insect pests are those which are normally associated with poor hygiene or damp conditions and tend to feed on fungal growth or broken grain rather than directly attacking whole grain. They were detected more frequently than the major pests, with fungus feeding beetles (*A. advena, T. stercorea* or *Crytophagus* spp.) present in 18.4% of stores; spider beetles (*Ptinidae*) in 36.0%; and moths (*Ephestia, Endrosis* or *Hofmannophila*) in at least 14.7% - 26.8% if unconfirmed occurrences are included. Overall, one or more of these species were detected in 50.9% of stores and nearly three-quarters of these detections were in the grain. Since the presence of any of these species could lead to rejection of the grain (on the basis of 'no live insects'), they would seem to pose an appreciable economic risk.

The status of psocids as a pest is perhaps debatable, but certainly if they are present in large numbers they may lead to rejection of grain. They were found in 54.8% of stores and over three-quarters of these detections were in grain. As with the secondary pests discussed above, psocids are generally associated with damp conditions or poor hygiene and thus their occurrence can be restricted by attention to the ingress of moisture, either from leaks or condensation, and removal of grain residues.

Mites are commonly found in association with stored grain and in this survey were recorded from 81.3% of the stores, with most (84.4%) of these detections occurring in the grain. It is important to remember that only the presence of mites was recorded, not the number, and therefore a detection does not imply that mites were sufficiently numerous to be considered an infestation. The three most common species were *Acarus siro*, *Glycyphagus destructor* and *Tyrophagus longior*, identified from 59.0%, 51.2% and 15.9% of stores respectively.

Glycyphagus spp. were found less frequently in grain that had been treated with insecticide than in untreated grain, but *Acarus* spp. and *Tyrophagus* spp. were found with similar frequency in treated and untreated grain.

Results of insecticide resistance tests

The doses of insecticide used in these tests were designed to be just sufficient to kill all normal or susceptible insects and therefore, although survival demonstrates an increased tolerance, it does not imply that the insects would survive a treatment at the recommended field rate. However, insects with the ability to survive these tests are likely to be more difficult to control and may reduce the effective life of a residual treatment.

The results of organophosphorus insecticide resistance tests on the major beetle pests collected during the survey showed that the ability to survive these tests (i.e. resistance) is widespread in *O. surinamensis*, but infrequent in *Cryptolestes* and *Sitophilus*. With *O. surinamensis*, there is evidence of resistance to all organophosphorus insecticides currently available for use on grain. There is little evidence of resistance in any of the species to the fumigants phosphine and methyl bromide.

The origins of the resistances and the reasons for the differences between the species remain unclear and require further investigation. There is, for example, no evidence that current insecticide usage in commercial stores is related to the resistances found.

The mite resistance tests differed from the insect tests in that the mites were exposed for 14 days to a dose equivalent to twice that recommended for grain treatment. Thus the ability to survive these tests is very likely to pose control problems. Mites were tested for resistance only to pirimiphos-methyl. Of the mite populations tested, 71% of *Acarus siro* and 11% of *Glycyphagus destructor* were found to be resistant. For *Tyrophagus*, all *T. putrescentiae* populations were resistant, whereas all *T. longior* were susceptible. In total, resistant mites were found in 45% of stores, with resistant strains of *Acarus siro* being found in 39% of the stores.

The need for further research

Whilst research and development are providing significant advances in storage strategies which avoid the use of insecticides, it seems likely that chemical control will be necessary in some circumstances for the foreseeable future. For example a surface treatment may be required to control mites in a cooled bulk of grain; admixture allows rapid disinfestation when fumigation is impractical; and residual populations hidden in the fabric of the store or machinery may need to be eradicated by spraying. Thus there is a need for research to provide strategies which will control resistant pests and avoid the further development of resistance.

The definition of insecticide resistance, as used in this report, follows that given by the FAO and WHO. The method used to detect resistance in insects follows that recommended by the FAO, and this has been included in the test methods proposed recently (1990) by IRAC. These tests form a fundamental part of resistance monitoring and further research is necessary to extend their range to encompass those pest/insecticide combinations for which no test is currently available.

The resistance tests give warning of impending or existing problems and allow strategies to combat resistance to be put into place. They do not necessarily provide a means of determining whether or not a particular insecticide treatment will be effective. This is a difficult problem because, for example, a degree of resistance which is sufficient for insects to survive a relatively brief contact with the treated structure of a store may not be sufficient for them to survive prolonged contact with treated grain. Other aspects, such as the formulation of the insecticide and the temperature, also need to be considered. There is, therefore, a need for a method of confirming whether or not a particular insecticide treatment will be effective in a given situation. Confirmation might be achieved by prior knowledge of the effect of a particular resistance gene, in which case a method of identifying the gene is required, or, empirically, by an assessment of the ability of the population to survive the intended treatment. The development of such a system would require a substantial amount of research, but it would benefit both the grain trade and the agrochemical industry.

The relationship between the number of insects detected by static traps and the number of insects present in the grain is, at present, unknown. The ability to estimate the population size from the trap catch would help storekeepers to decide what sort of remedial action was necessary. Further research on this subject is needed to allow the use of static traps to be fully incorporated in safe storage strategies.

The information provided by the present study of commercial grain stores, and by the previous one which looked at farm grain stores, has demonstrated the efforts made by storekeepers to maintain the quality of grain, and the need for continual vigilance to avoid the development of pest problems. It has also high-lighted some areas where further research would be of benefit. Now that a baseline has been set up, follow-up exercises should be carried out at regular intervals so that changes in storage practices and problems can be monitored. In addition the exercises should be extended to include other premises where stored products are at risk from attack by insects and mites and particularly those premises which are part of, or directly linked to, the grain trade.

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GLOSSARY

Abbreviations

ADAS	Agricultural Development and Advisory Service of MAFF.
Conc.	concentration
cp-m	chlorpyrifos-methyl
E	Eastern Region of MAFF.
ec	emulsifiable concentrate
etr	etrimfos
FAO	Food and Agriculture Organisation of the United Nations
fen	fenitrothion
GIFAP	Groupement International des Associations Nationales de Fabricants de Produits Agrochimiques.
HGCA	Home-Grown Cereals Authority
IBAP	Intervention Board for Agricultural Produce.
IRAC	Insecticide Resistance Action Committee of GIFAP
M & W	Midlands and Western Region of MAFF
MAFF	Ministry of Agriculture, Fisheries and Food
mal	malathion
MeBr	methyl bromide
meth	methacrifos
N	Northern Region of MAFF
PH_3	phosphine
p-m	pirimiphos-methyl
Ref.	reference number of site and store
SE	South Eastern Region of MAFF
spp.	species
SW	South Western Region of MAFF
wp	wettable powder
WSB	Wildlife and Storage Biology Discipline of ADAS

Common and Scientific Names for Insects and Mites (after Seymour, 1989)

Acarus farris	a mite
Acarus immobilis	a mite
Acarus siro	grain mite, flour mite
Ahasverus advena	foreign grain beetle

Cerobasis guestfalica	bark psocid or louse
Cryptolestes ferrugineus	rust-red grain beetle
Cryptophagus spp.	mould beetles
Ectopsocus briggsi	a psocid or booklouse
Endrosis sarcitrella	white-shouldered house moth
Ephestia elutella	warehouse moth, cacao moth
Glycyphagus destructor	cosmopolitan food mite, grocer's itch mite.
Glycyphagus domesticus	house mite, grocer's itch mite
Glycyphagus michaeli	a mite
Glycyphagus ornatus	a mite
Hofmannophila pseudospretella	brown house moth
Lachesilla pedicularia	cosmopolitan grain psocid
Lepinotus patruelis	black domestic psocid, black cereal psocid
Lepinotus reticulatus	black domestic psocid
Liposcelis bostrychophila	stored product psocid
Liposcelis corrodens	outhouse psocid
Liposcelis decolor	a psocid or booklouse
Liposcelis entomophila	a psocid or booklouse
Oryzaephilus surinamensis	saw-toothed grain beetle
Psocoptera	psocids, booklice, barklice, dustlice.
Ptinus fur	white-marked spider beetle
Ptinus pusillus	a spider beetle
Ptinus tectus	Australian spider beetle
Rhyzopertha dominica	lesser grain borer (a beetle)
Sitophilus granarius	grain weevil
Sitophilus oryzae	rice weevil
Sitophilus zeamais	maize weevil

Tribolium castaneum	rust-red flour beetle
Tribolium confusum	confused flour beetle
Trogium pulsatorium	large pale booklouse
Typhaea stercorea	hairy fungus beetle
Tyrophagus longior	grainstack mite, seed mite, straw mite.
Tyrophagus palmarum	a mite
Tyrophagus putrescentiae	mould mite, cheese mite
Tyrophagus similis	grassland mite

<u>Insecticides, common and proprietary names</u>

chlorpyrifos-methyl	Cooper Graincote (Wellcome), Reldan (Dow)
etrimfos	Satisfar (Sandoz)
fenitrothion	Fenitrothion (Chiltern, Wellcome), Dicofen (PBI), also a constituent of Turbair Grain Store Insecticide (PBI).
malathion	not marketed for grain store use
methacrifos	Damfin (Ciba-Geigy)
pirimiphos-methyl	Actellic (ICI)

APPENDIX 1

INFORMATION GATHERING EXERCISE COMMERCIAL GRAIN STORES ENGLAND & WALES 1988
FACT-SHEET PART A - THE SITE

1. REFERENCE NUMBER: ....

2. COMPANY NAME: ....

3. SITE NAME: ....

4. SITE ADDRESS: ....
....
....
....

5. COUNTY: ....

6. MAFF REGION (circle): N M+W E SE SW Wales

7. MAP REFERENCE: ....

8. MAFF ADVISER: ....

9. VISIT POSSIBLE? (circle): Yes No
IF 'No' STATE REASON: ....

10. DATE OF VISIT: ....

SITE DESCRIPTION - FUNCTION

11. TYPE OF SITE (circle(s)):
Commercial trading
Co-operative
Government owned
Port
Other (specify) ....

12. USE OF SITE (circle(s)):
(Re grain only)
Solely grain storage
Storage and milling
Storage and malting
Storage and seed cleaning
Other (specify) ....

13. WHAT INFESTABLE COMMODITIES OTHER THAN CEREAL GRAIN HAVE BEEN STORED ON THIS SITE IN THE LAST 12 MONTHS ? (circle(s)):
Carobs
Peas/beans
Oilseed rape
Other (specify) ....

14. SOURCE OF GRAIN CURRENTLY IN STORE (circle(s)):

Source	Percent of total grain in store										
Home-grown - farms :	0	10	20	30	40	50	60	70	80	90	100
Home-grown - other stores:	0	10	20	30	40	50	60	70	80	90	100
Imports :	0	10	20	30	40	50	60	70	80	90	100
Unknown :	0	10	20	30	40	50	60	70	80	90	100

15. INTENDED FATE OF GRAIN CURRENTLY IN STORE (circle(s)):
Export
Sell to Intervention
Already in Intervention
Food manufacture
Flour mill
Feed mill
Seed
Malting
Back to farm
Other grainstores
Unknown
Other fate (specify) ....

SITE DESCRIPTION - SIZE

16. GRAIN STORAGE CAPACITY:

Type of storage	Number of structures	Total capacity (tonnes)
Floor-store :	....	....
Bins - internal:	....	....
Bins - external:	....	....
Other (specify)	....	....
	Grand total:	________

17. HOW MUCH GRAIN IN STORE NOW ? (tonnes):

	Wheat	Barley	Oats	*Other (specify) ______	______	TOTAL
Floor-store:	....	....	....	....	....	....
Bins-intern:	....	....	....	....	....	....
Bins-extern:	....	....	....	....	....	....
Other :	....	....	....	....	....	....
TOTAL :	______	______	______	______	______	______

* Other cereal grain if more than 100t in store

18. WHAT WAS GRAIN THROUGH-PUT FOR LAST 12 MONTHS ? :
(If this figure unavailable request figure for LAST TRADING YEAR and also complete Q19)

Commodity	Tonnes
Wheat :	....
Barley :	....
Oats :	....
*Other (specify)	
.... :	....
.... :	....
TOTAL :	________

* Other cereal grain if more than 100t

19. IF DATA IN Q18 IS FOR LAST TRADING YEAR, SPECIFY MONTH THAT LAST TRADING YEAR BEGAN : ....

INTAKE AND INSPECTION

20. HOW WAS THE GRAIN NOW IN STORE DELIVERED ? (circle(s)) :

Transport		Percent of grain now in store										
Lorry - own	:	0	10	20	30	40	50	60	70	80	90	100
Lorry - contractor's	:	0	10	20	30	40	50	60	70	80	90	100
Railway wagon	:	0	10	20	30	40	50	60	70	80	90	100
Tractor/trailer	:	0	10	20	30	40	50	60	70	80	90	100
Other (specify)	:	0	10	20	30	40	50	60	70	80	90	100

21. WAS THE GRAIN NOW IN STORE EXAMINED FOR INFESTATION AS IT CAME IN ? (circle) : Yes No

IF 'Yes' :-

a) HOW AND WHEN WAS IT INSPECTED ? (circle(s)) :

Method		Time of Inspection	
		Before Unloading	During unloading
Spear/sieve	:	***	***
Vacuum/sieve	:	***	***
Sieve	:	***	***
Visual	:	***	***
Other (specify)	:	***	***

b) HOW MANY SAMPLES WERE TAKEN PER INTAKE UNIT? (circle(s)) :

Unit		Number of samples								
Lorry - own	:	1	2	3	4	5	6	7	8	>8
Lorry - contractor's	:	1	2	3	4	5	6	7	8	>8
Railway wagon	:	1	2	3	4	5	6	7	8	>8
Tractor/trailer	:	1	2	3	4	5	6	7	8	>8
Other (specify)	:	1	2	3	4	5	6	7	8	>8

22. WHAT LEVEL OF PEST NUMBERS IS ACCEPTABLE IN GRAIN UPON INTAKE ? (circle) :

Pest		Level of pest numbers		
Insects	:	Nil	Small nos.	Large nos.
Mites	:	Nil	Small nos.	Large nos.

23. HAS GRAIN BEEN REJECTED ON INTAKE BECAUSE OF INFESTATION IN THE LAST 12 MONTHS ? (circle): Yes No

If 'Yes' :-

a) HOW MUCH GRAIN WAS REJECTED ? (tonnes) : ....

b) WHAT WAS THE MAJOR SOURCE OF REJECTED GRAIN ? (circle) :

Farms
Other stores
Imports
Other (specify).............

GRAIN CLEANING, DRYING & COOLING

(N.B. Please see notes to ensure distinction between equipment for drying and cooling).

24. GRAIN CLEANER(S) ON SITE (circle(s)) :

	Present and used in last 12 months	Present but unused in last 12 months	Absent
Aspirated :	***	***	***
Sieve(s) :	***	***	***
Aspirated sieve :	***	***	***
Other (specify) .... :	***	***	***

25. GRAIN DRYER(S) ON SITE (circle(s)) + estimated tonnes dried) :

	Present and used in last 12 months	Estimated throughput in last 12 months	Present but unused in last 12 months	Absent
Heated - continuous :	***	....	***	***
Heated - batch :	***	....	***	***
(Near) ambient-bulk :	***	....	***	***
(Near) ambient - bin:	***	....	***	***
Dehumidifier - bulk :	***	....	***	***

26. GRAIN COOLER(S) ON SITE (circle(s)) :

	Present and used in last 12 months	Present but unused in last 12 months	Absent
Refrigerated :	***	***	***
Non-refrigerated:-			
Ducted system :	***	***	***
Spearator :	***	***	***
Ventilated floor :	***	***	***

27. IF GRAIN COOLER PRESENT (excluding spearator) :-

a) WHAT CAPACITY OF THE STORES CAN BE COOLED AT ANY ONE TIME ?
(tonnes): ....

b) HOW ARE THE FANS CONTROLLED ? (circle(s)) :

Manually
Automatically - normal thermostat
" - differential thermostat
" - combination of thermostat & humidistat
" - timer

INSECT CONTROL

28. HAS THERE BEEN AN INSECT INFESTATION ON THIS SITE IN THE LAST 12 MONTHS ?
(circle) : Yes No
IF 'Yes' SPECIFY SPECIES (if known) : ....

29. HAS THERE BEEN A MITE INFESTATION ON THIS SITE IN THE LAST 12 MONTHS ?
(circle) : Yes No

30. DO YOU CONSIDER AN INFESTATION IN STORE TO BE ... (circle) :

	Very serious	Serious	Of some concern	Of little concern
Insects :	***	***	***	***
Mites :	***	***	***	***

31. WHAT DO YOU CONSIDER TO BE YOUR MOST SIGNIFICANT INSECT PEST ?
(Specify) : ....

32. WHAT INSECT DETECTION METHODS HAVE BEEN USED ON THIS SITE IN THE LAST 12 MONTHS ? (circle(s)) :

Spear/sieve
Vacuum/sieve
Sieve
Probe trap
Pitfall trap
Bait bag
Visual
Other (specify) ....
None

33. HAS THE FABRIC OF ANY OF THE STORES OR ANY MACHINERY IN THEM BEEN TREATED WITH INSECTICIDE DURING THE LAST 12 MONTHS ? (circle) : Yes No
IF 'Yes' :-

a) WHAT WAS THE REASON FOR TREATMENT ? (circle) :
Prophylaxis
Known infestation

b) WHAT INSECTICIDES WERE USED ON THE FABRIC OF THE STORE(S) OR MACHINERY IN THE LAST 12 MONTHS ? (circle(s)) :

	Compound						
Formulation	CPM	Etrim	Fen	Mal	PM	Don't know	Other (specify)
Spray (EC) :	***	***	***	***	***	***	....
Spray (WP) :	***	***	***	***	***	***	....
Dust :	***	***	***	***	***	***	....
Smoke :	***	***	***	***	***	***	....
Other (specify) .... :	***	***	***	***	***	***	....
Don't know :	***	***	***	***	***	***	....

(Abbreviations used :
CPM = Chlorpyrifos-methyl   Mal = Malathion
Etrim = Etrimfos   PM = Pirimiphos-methyl
Fen = Fenitrothion)

34. HAS ANY GRAIN BEEN TREATED WITH INSECTICIDE OR FUMIGANT ON THIS SITE IN THE LAST 12 MONTHS ? (circle) :

Insecticide	:	Yes-all	Yes-part	No
Fumigant	:	Yes-all	Yes-part	No

IF 'Yes' :-

a) WHAT WAS THE REASON FOR TREATMENT ? (circle) :

Insecticide	:	Prophylaxis	Known infestation
Fumigant	:	Prophylaxis	Known infestation

b) HOW MUCH GRAIN WAS TREATED ON THIS SITE IN THE LAST 12 MONTHS ? :

Commodity		Tonnes	Estimated percent of throughput	Intended fate of treated grain (see Q15 for options)
Wheat	:	....	....	....
Barley	:	....	....	....
Oats	:	....	....	....
Other (specify)				
....	:	....	....	....
....	:	....	....	....

c) WHAT INSECTICIDES OR FUMIGANTS WERE USED ON GRAIN IN THE LAST 12 MONTHS ? (circle(s)) :

		Compound						
Formulation		CPM	Etrim	Mal	Methac	PM	Don't know	Other (specify)
Spray	:	***	***	***	***	***	***	....
Dust	:	***	***	***	***	***	***	....
Other (specify)								
....	:	***	***	***	***	***	***	....
Don't know	:	***	***	***	***	***	***	....
Fumigant	:	Phosphine		Methyl bromide		Other (Specify).........		

(See Q33 for abbreviations used,
Methac = Methacrifos)

d) IF THE GRAIN WAS ADMIXED, HOW WAS IT DONE ? (circle(s)) :

Surface only
Bulk by machine
Other (specify) : ....

35. WHO CARRIED OUT THE INSECT CONTROL TREATMENTS? (circle):

	Fabric treat	Grain admix.	Grain surface	Fumig.
Own staff:	***	***	***	***
Other :	***	***	***	***

RODENT CONTROL

36. HAS THERE BEEN A RODENT INFESTATION ON THIS SITE IN THE LAST 12 MONTHS ? (circle) : Yes No

IF 'Yes', WHICH SPECIES ? :
(circle and specify species if known)
Rats : ....
Mice : ....

37. HAS A RODENTICIDE TREATMENT BEEN UNDERTAKEN ON THIS SITE DURING THE LAST 12 MONTHS ? (circle) : Yes No

IF 'Yes' :-

a) AGAINST WHICH SPECIES ? :
(circle and specify species if known)
Rats : ....
Mice : ....

b) WHO UNDERTOOK RODENT CONTROL TREATMENTS ? (circle(s)):
Owner/employees
Contractor
Local Authority
Other (specify) : ....

c) ON HOW MANY OCCASIONS WERE RODENTICIDE TREATMENTS UNDERTAKEN IN THE LAST 12 MONTHS ? (number) : ....

d) WHAT WAS THE ESTIMATED FULL COST OF TREATMENTS OVER THE LAST 12 MONTHS ? (pounds) : ....

e) WHAT RODENTICIDES WERE USED ? (circle(s)) :

	Compound							
Formulation	Bromad	Calcif	Chlor	Coum	Difen	Warf	Don't know	Other (specify)
Grain bait :	***	***	***	***	***	***	***	....
Pelleted bait :	***	***	***	***	***	***	***	....
Wax block :	***	***	***	***	***	***	***	....
Liquid :	***	***	***	***	***	***	***	....
Tracking dust :	***	***	***	***	***	***	***	....
Contact gel :	***	***	***	***	***	***	***	....
Other (specify) ....:	***	***	***	***	***	***	***	....
Don't know :	***	***	***	***	***	***	***	....

(Abbreviations used :
Bromad = Bromadiolone
Calcif = Calciferol
Chlor = Chlorophacinone
Coum = Coumatetralyl
Difen = Difenacoum
Warf = Warfarin)

f) HOW EFFECTIVE WERE THE TREATMENTS ? (circle) :

Ineffective
Partially effective
Very effective

g) WERE ANY OTHER METHODS USED TO CONTROL RODENTS ?
(circle) : Yes No

IF 'Yes' SPECIFY METHOD : ....

BIRD CONTROL

38. HAS THERE BEEN A BIRD INFESTATION ON THIS SITE IN THE LAST 12 MONTHS ? : (circle) : Yes No

IF 'Yes', WHICH SPECIES ? : ....
....
....

39. HAS AN ATTEMPT BEEN MADE TO CONTROL A BIRD INFESTATION IN THE LAST 12 MONTHS ? (circle) : Yes No

IF 'Yes' :-

a) SPECIFY THE METHOD(S) USED : ....
....
....

b) WHO UNDERTOOK BIRD CONTROL ? (circle(s) :

Owner/employees
Contractor
Local authority
Other (specify) ....

c) HOW MANY TIMES IN THE LAST 12 MONTHS WERE ATTEMPTS MADE TO CONTROL BIRDS ? (number) ....

d) HOW EFFECTIVE WERE THE BIRD CONTROL METHODS ? (circle) :

Ineffective
Partially effective
Very effective

ADVICE

40. FROM WHICH SOURCES HAVE YOU SOUGHT AND/OR GAINED ADVICE ON GRAIN STORAGE IN THE LAST 12 MONTHS ? (circle) :

Source		Type of advice		
		Pest control	Other (specify)	
Chemical company	:	***	***	....
Other agricultural company	:	***	***	....
ADAS staff	:	***	***	....
ADAS leaflets	:	***	***	....
Consultants	:	***	***	....
Other (specify)				
....	:	***	***	....
....	:	***	***	....

41. HOW MANY STORES INSPECTED ON THIS SITE ? (circle) : (i.e. number of 'Part-Bs' completed for this site)

0 1 2 3 4

APPENDIX 2

INFORMATION GATHERING EXERCISE COMMERCIAL GRAIN STORES ENGLAND & WALES 1988

FACT SHEET PART B - THE STORE INSPECTED
(N.B: External bins are not to be inspected)

42. REFERENCE NUMBER : ....

43. STORE INSPECTION NUMBER (circle) : 1st 2nd 3rd 4th

44. STORE IDENTIFICATION : ....

45. SITE NAME : ....

46. MAFF REGION (circle) : N M+W E SE SW Wales

47. MAFF ADVISER : ....

48. DATE OF VISIT : ....

DESCRIPTION OF THE STORE

49. TYPE & CAPACITY OF THE STORE :

Type of storage (circle(s))		Number of sub-divisions	Total capacity (tonnes)
Floor-store	:	....	....
Bins - internal	:	....	....
Other (specify)	:	....	....
		Grand total :	

50. IF BIN(S) SPECIFY FABRIC : ....

51. IF FLOOR STORE :-

a) WHAT TYPE OF BUILDING IS IT ? (circle) :

Hangar
Purpose built
Other (specify) ....

b) IS GRAIN WALLING PRESENT ? (circle) : Yes No

IF 'Yes' :-

i) WHAT IS THE FABRIC OF THE GRAIN WALLING ?
(specify) : ....

ii) IS ANY OF THE GRAIN SURCHARGED ? (circle) : Yes No
(i.e. heaped well above grain walling)

52. CONTENTS OF THE STORE:

a) CEREAL GRAIN PRESENT:

Commodity (circle(s))		Tonnes on floor	Tonnes in bins	Tonnes total	Inspected ? (circle(s)) floor	bins
Wheat	:	......	......	......	Yes	Yes
Barley	:	......	......	......	Yes	Yes
Oats	:	......	......	......	Yes	Yes
Other (specify)	:					
....	:	......	......	......	Yes	Yes
....	:	......	......	......	Yes	Yes
			Grand total :	______		

b) OTHER INFESTABLE COMMODITIES PRESENT :

Commodity (circle)		Tonnes
Carobs	:	....
Peas/Beans	:	....
Oilseed rape	:	....
Other (specify)		
....	:	....
....	:	....

GRAIN COOLING

53. DOES THE STORE HAVE A COOLING SYSTEM (other than spearator) ?
(circle) : Yes No

IF 'Yes)' :-

HAS THE GRAIN NOW IN STORE BEEN COOLED ? (circle) : Yes No

GRAIN MONITORING

54. IS THE TEMPERATURE OF THE GRAIN IN THIS STORE MEASURED ?
(circle) : Yes No

IF 'Yes' :-

a) HOW IS THE TEMPERATURE MEASURED ? (circle) :

Fixed sensors
Spot measuring

b) WAS IT MEASURED ON INTAKE ? (circle) : Yes No

c) AFTER INTAKE HOW OFTEN IS IT MEASURED ? (circle) :

Daily
Weekly
Monthly
Less than monthly
Never

55. IS THE MOISTURE CONTENT OF THE GRAIN IN THIS STORED MEASURED ?
(circle) : Yes No

IF 'Yes' :-

a) HOW IS THE MOISTURE CONTENT MEASURED ? (circle)

Oven
Meter (specify) ....

b) WAS IT MEASURED ON INTAKE ? (circle) : Yes No

c) AFTER INTAKE HOW OFTEN IS IT MEASURED ? (circle) :

Daily
Weekly
Monthly
Less than monthly
Never

56. IS THE GRAIN CHECKED FOR THE PRESENCE OF INSECTS OR MITES ?
(circle) : Yes No

IF 'Yes' :-

a) WHAT METHOD(S) ARE USED ? (circle(s)) :

Spear/sieve
Vacuum/sieve
Sieve
Probe trap
Pitfall trap
Bait bag
Visual
Other (specify) : ....

b) WAS IT CHECKED ON INTAKE ? (circle): Yes No

c) AFTER INTAKE HOW OFTEN IS IT CHECKED ? (circle) :

Daily
Weekly
Monthly
Less than monthly
Never

57. ARE YOU AWARE OF ANY PESTS IN THIS STORE ? (circle) :

Insects	:	Yes	No
Mites	:	Yes	No
Rodents	:	Yes	No
Birds	:	Yes	No

INSECTICIDE USE

58. HAS THE FABRIC OF THE STORE OR ANY MACHINERY IN IT BEEN TREATED WITH INSECTICIDE DURING THE LAST 12 MONTHS ? (circle) : Yes No
IF 'Yes' :-

a) WHAT WAS THE REASON FOR TREATMENT ? (circle) :

Prophylaxis
Known infestation

b) WHAT INSECTICIDES WERE USED ON THE FABRIC OF THE STORE OR MACHINERY IN IT IN THE LAST 12 MONTHS ? (circle(s)) :

		Compound						
Formulation		CPM	Etrim	Fen	Mal	PM	Don't know	Other (specify)
Spray (EC)	:	***	***	***	***	***	***	....
Spray (WP)	:	***	***	***	***	***	***	....
Dust	:	***	***	***	***	***	***	....
Smoke	:	***	***	***	***	***	***	....
Other (specify)	:	***	***	***	***	***	***	....
Don't know	:	***	***	***	***	***	***	....

(See Q33 for abbreviations used)

59. HAS ANY GRAIN NOW IN THIS STORE BEEN TREATED WITH INSECTICIDE OR FUMIGANT IN THE LAST 12 MONTHS ? (circle) :

Insecticide :	Yes-all	Yes-part	No
Fumigant :	Yes-all	Yes-part	No

IF 'Yes' :-

a) WHAT WAS THE REASON FOR TREATMENT ? (circle) :

Insecticide	:	Prophylaxis	Known infestation
Fumigant	:	Prophylaxis	Known infestation

b) HOW MUCH OF THE GRAIN NOW IN THIS STORE HAS BEEN TREATED ON THIS SITE IN THE LAST 12 MONTHS ?

Commodity (circle(s))		Tonnes on floor	Tonnes in bins	Tonnes total	Intended fate of treated grain
Wheat	:	....	....	....	....
Barley	:	....	....	....	....
Oats	:	....	....	....	....
Other (specify)					
....	:	....	....	....	....
....	:	....	....	....	....
			Grand total	_______	

c) WHAT INSECTICIDES OR FUMIGANTS WERE USED ON THIS GRAIN IN THE LAST 12 MONTHS ? (circle(s)) :

		Compound						
Formulation		CPM	Etrim	Mal	Methac	PM	Don't know	Other (specify)
Spray	:	***	***	***	***	***	***	....
Dust	:	***	***	***	***	***	***	....
Other (specify)								
....	:	***	***	***	***	***	***	....
Don't know	:	***	***	***	***	***	***	....

Fumigant : Phosphine Methyl-bromide Other (specify) ....

(See Q33 for abbreviations used,
Methac = Methacrifos)

d) IF THE GRAIN WAS ADMIXED, HOW WAS IT DONE ? (circle(s)) :

Surface only
Bulk by machine
Other (specify) : ....

INSECTS & MITES DETECTED

60. INSECTS AND MITES DETECTED IN THE STORE :

Notes : a) PLEASE circle all detection methods used
b) Circle against each species detected, in the appropriate column to indicate method by which detected.

SPECIES	METHOD OF DETECTION					
	Visual on structure	Sieve	Baitbag on grain	Baitbag on structure	Pitfall	Probe
O. surinamensis:	***	***	***	***	***	***
Cryptolestes sp:	***	***	***	***	***	***
R. dominica :	***	***	***	***	***	***
Sitophilus sp :	***	***	***	***	***	***
Tribolium sp :	***	***	***	***	***	***
A. advena :	***	***	***	***	***	***
T. stercorea :	***	***	***	***	***	***
Ptinidae :	***	***	***	***	***	***
Ephestia sp :	***	***	***	***	***	***
Endrosis sp :	***	***	***	***	***	***
Hofmannophila sp:	***	***	***	***	***	***
Psocoptera :	***	***	***	***	***	***
Acarus sp :	***	***	***	***	***	***
Glycyphagus sp :	***	***	***	***	***	***
Tyrophagus sp :	***	***	***	***	***	***

RODENTS & BIRDS DETECTED

61. RODENTS AND BIRDS DETECTED IN THE STORE:
(Note: Circle against animals detected, in appropriate 'evidence' column)

ANIMAL	EVIDENCE OF PRESENCE			
	Species (if known)	Animal sighted*	Droppings	Physical signs - (specify)**
Rat	...........:	***	***	*** ....
Mouse	...........:	***	***	*** ....
Pigeon	...........:	***	***	*** ....
Sparrow	...........:	***	***	*** ....
Starling	...........:	***	***	*** ....
Other (specify)				
........................:		***	***	*** ....
........................:		***	***	*** ....

Notes: * Animal sighted includes dead bodies
** Physical signs include for example : Fresh run-ways
Damage
Smell
Urine post
Grease marks
Nests

Please return completed fact-sheets to A.J. Prickett, Slough Laboratory.

APPENDIX 3

INSPECTION PROTOCOL
PEST MONITORING INFORMATION GATHERING EXERCISE
1988 - COMMERCIAL GRAIN STORES

Introduction

This is the second information gathering exercise involving pest infestation and pesticide resistance in premises storing cereal grain. The first, concerning farm grain stores, took place in 1987 and its successful completion reinforced the case for the usefulness of this type of exercise.

The exercise forms part of the MAFF Chief Scientist's commissioned programme of work, under Programme B3 "Arthropod Pests and Micro-organisms of Stored Food". The costs of the present exercise are shared equally between MAFF and the Home-Grown Cereals Authority, via a Levy-funded research grant.

The details of the exercise were worked out in consultation with Dr K B Wildey (as a representative of the Wildlife and Storage Biology Discipline), Dr A MacNicoll (Tolworth Laboratory) and the appropriate staff of the Slough Laboratory. The success of the 1987 exercise has meant that the 1988 "Fact Sheet" is even more comprehensive than its predecessor and this has happened as recognition of its potential usefulness has increased.

Definition and Objectives

For this exercise a "commercial grain store" is defined as one belonging to an organisation/person that trades (buys and sells), or stores grain, but excluding those whose major commercial activity is producing a finished product; we have also excluded growers of grain and producers of feed. Since they are under a similar management to the commercial stores, we have included under this heading the government owned IBAP stores.

The objectives are:

i) To determine the incidence of infestation by vertebrates and invertebrates in commercial grain stores.

ii) To collect insects and mites for resistance testing and to test for resistance to those compounds used on stored grain.

iii) To collect information about the storage practices used.

iv) To collate, analyse and draw conclusions on the relationship between storage practice and infestation from the data collected for objectives i) to iii).

<u>Notes for completion of fact sheet</u>

The aim is to visit all sites on the address lists. Up to four structures (floor stores or internal bins) are to be inspected at each site, as indicated on the address list. A free-standing internal bin counts as one structure but a group of bins with shared walls also counts as one structure. External bins/silos are not to be inspected for infestation, but details of them should be included in fact sheet 'A'.

This exercise is concerned with cereal grain only (not rape) and the questions and answers should reflect this unless otherwise stated.

There are two types of fact sheet:

Fact sheet "A" is for details of the SITE.

Fact sheet "B" is for details of the STORE inspected, one should be completed for each store/structure inspected.

The fact sheets have been designed so that most questions can be completed by circling the relevant answer. Where it was not practical to repeat text, three asterisks (***) have been used and these should be circled as appropriate.

If the site has only one store/structure for cereal grain storage, then some of the questions in Part A (the site) may appear to be the same as questions in Part B (the store). In fact only questions 16 & 49, 17 & 52a, and 33 & 58 are the same in both parts (except that 52a requires inspection details). Questions 34 & 59 are NOT the same since Part A refers to the last 12 months and Part B refers to the grain now in store. Questions 21a, 32 and 56a on infestation checks differ since the first refers to intake, the second to the last 12 months and the third to grain now in store.

Completed fact sheets should be returned to A J Prickett, Slough Laboratory. Please return them as soon as possible - do not wait until the end of the exercise. If a site cannot be visited, complete questions 1-9, state the reason, and return the fact sheet to Slough.

Part A - The Site

1 Reference number: as supplied with address list.

2 Company name: the name of the company that manages the site, not necessarily the same as in the address list.

3 Site name: as underlined in the address list, not the true name of the site.

4 Site address: correct postal address.

5 County: of site, not necessarily the same as for the postal address.

6 MAFF Region: of site.

7 Map reference: 2 letters and 4 digits, e.g. SU9779.

8 MAFF adviser.

9 Visit possible: state reason if visit not possible.

10 Date of visit: first visit

11 Type of site.

12 Use of site: with respect to cereal grain only.

13 Other infestable commodities: by insects or mites.

14 Source of grain: to nearest 10%, should add up to 100.

15 Intended fate of grain:

Site description - size

16 Grain storage capacity: maximum potential storage capacity, even if currently used for other purposes.
Number of structures: for floor stores this is the number of discrete buildings; for bins this is the number of bins.

17 Grain in store: If cereal grain other than wheat, barley or oats is stored in significant quantity (ie more than 100 tonnes) write name(s) at top of columns headed "other (specify)".

18 Grain through-put: Please try to get figures for last 12 months before resorting to last trading year. If the figures are for the last trading year please circle these words on the fact sheet.

19 If last trading year: Specify month to indicate that it was not possible to get figure for last 12 months throughput in Q.18.

Intake and inspection

20 How grain delivered: to nearest 10%, should add up to 100.

21 Grain examined as it came in:

21a How and when: before unloading - still on transport
during unloading - whilst or immediately after unloading, i.e. when grain is entering or has just entered the storage facility.

21b How many samples: approximate average number of samples taken per lorry load, trailer-load etc.

22 Acceptable pest numbers:

23 Rejected grain:

23a How much:

23b Major source:

Grain cleaning, drying and cooling

24 Grain Cleaner: The full (?) list of cleaners is:
cleaner auger
aspirated
sieve (combination)
indented cylinder
indirect band wild oat separator
needle cylinder
optical separator
vertical cylindrical sieve (rotary)
aspirated sieve

25 Grain Dryer: problems may arise in visually distinguishing between near-ambient drying and non-refrigerated cooling. Since the storekeeper may conceivably use the same system for both cooling and drying, ask him for what purpose he uses the system!

26 Grain cooler: see Q.25 above

27a Capacity cooled:

27b How contolled:

Insect control

28 Insect infestation: i.e. has the storekeeper been aware of pests.

29 Mite infestation:

30 How consider infestation: give storekeeper the options.

31 Most significant pest: i.e. that which the storekeeper considers to be his most serious threat.

32 Detection methods:

33 Fabric treatments:

33a Reason: prophylaxis suggests a policy decision to use insecticide whether or not insects are known to be present.

33b Insecticides used: note that sprays are not necessarily emulsifiable concentrates or wettable powders, other formulations may be in use.

34 Grain treatments:

34a Reason:

34b How much: for 'fate' use abbreviations from Q.15

34c Insecticides used:

34d How admixed:

35 Who treated: refers to both fabric and grain treatments.

<u>Rodent control</u>

36 Rodent infestation: use abbreviations to specify species e.g. RN RR MD etc (common names are OK).

37 Rodenticide treatment:

37a Species:

37b Who treated:

37c How many: a treatment is defined as a course of rodenticide use.

37d Cost:

37e Rodenticides used:

37f Effectiveness:

37g Other methods:

<u>Bird control</u>

38 Bird infestation: common names are sufficient.

39 Control?:

39a Methods used:

39b Who did it:

39c How many times:

39d How effective:

<u>Advice</u>

40 Sources of advice:

<u>Store inspections</u>

41 Stores inspected: the number of Part "B"s completed for this site (up to 4 per site).

<u>Part B - The store inspected</u>

42 Reference number: as supplied with address list.

43 Store inspection number: to specify whether 1st, 2nd etc store inspected at this site. The same as that which you circle on the tear-off slips.

44 Store identification: Name, number etc by which the store is known, so that it can be positively identified in correspondence or a follow-up visit.

45 Site name: as underlined in address list.

46 MAFF region: of site.

47 MAFF adviser:

48 Date of visit:

Description of the store

49 Type & capacity: if floor store, sub-divisions = number of bays etc. if internal bins, subdivisions = number of bins.

50 Fabric of bins:

51a Type of floor store:

51b Grain walling?:

51b i Fabric of walling:

51b ii Grain surcharged:

52a Grain present: please remember to indicate whether inspected.

52b Other infestable commodities: (not to be inspected).

Grain cooling

53 Cooling system: if not obvious, ask storekeeper (see notes for Q25 & 26). "Has grain been cooled" refers to anywhere on that site, not necessarily in that store.

Grain monitoring

54 Temperature measured:

54a How measured:

54b On intake: i.e. before stored.

54c How often: if the answer is "daily" check that it refers to at least one week after intake.

55 Moisture content:

55a How measured:

55b On intake:

55c How often:

56 Checked for pests:

56a Methods:

56b On intake: i.e. before stored.

56c How often:

57 Aware of pests:

Insecticide use

58 Fabric treatment:

58a Reason:

58b Insecticides used:

59 Grain treatment:

59a Reason:

59b How much & fate: see Q.15 for "fate" categories - abbreviate as necessary.

59c Insecticides used:

59d How admixed:

Insects & mites detected

60 Inverts detected: PLEASE remember to circle the detection methods used.

Rodents & birds detected

61 Verts. detected: For species, common names are sufficient.

Guidelines for site visits

First vist: Assure the storekeeper that the data collected will be treated in confidence. You should also tell the storekeeper that he will receive a report detailing any problems encountered in his stores, and that at a later date each company will receive a summary of the findings of the exercise. The fact sheet should be completed (1 hour), the layout of the stores familiarised (up to 1 hour) and the traps put into position (4-5 hours for 20,000 tonnes). At some sites there may be a choice of stores that can be inspected; preference should be given to those stores containing grain, and empty stores should be inspected only as a last resort. Before inserting probe and pitfall traps in the grain, try to ensure that the grain is not going to be moved before the next visit. If there is any doubt ask the storekeeper to remove the traps, if possible keeping the probe and pitfall traps upright.

Safety

Commercial grain stores can be dangerous places; all advisers should be aware of the inherent instability of large bulks of grain and of the danger of grain walling collapsing. Great care should therefore be exercised when visiting the stores and the WSB Safety Code of Practice must be followed, paying particular attention to Section 7.4. Do not carry out an inspection on your own if there is any foreseeable hazard and, when visiting isolated stores, do make sure that someone knows where you are and when you expect to return.

Second visit 7-10 days after the first visit. Check and remove traps (3 hours for 20,000 tonnes). Discuss briefly with the storekeeper any problems you have detected. Remind the storekeeper that he will receive a report giving details of any pests found together with general advice on any problems encountered.

Equipment to be taken should include, traps, a white enamel tray, plastic bags, scissors or knife, string for securing the traps, bamboo marker canes, torch, collection tubes, notebook, and a small sieve for examining residues, spillages, sweepings etc.

Visual inspection and trapping. Before placing the traps a visual survey of the store should be made. This visual survey should be limited to the area used for grain storage. During the visual survey, the presence of vertebrate pest species should be recorded. All recent signs (droppings, smears, feathers, nests etc) will be regarded as confirmation of pest presence. If present, a sample of grain residues or other debris should be collected and taken back to the laboratory for microscope examination for mites.

Setting up traps

1) On Grain: For **flat grain** use 1 bait bag + 1 probe trap + 1 pitfall trap at each trapping point in a grid pattern.
For up to 5000 tonnes trapping points should be every 4-5 metres;
for 5 to 15,000 tonnes trapping points should be every 5-6 metres;
for more than 15,000 tonnes trapping points should be every 10 metres.
For **sloping grain**, as for flat grain but use only bait bags and probe traps (pitfalls cannot be used).

As a guide you may expect to use,
15-20 trap points for 5,000 tonnes.
20-30 trap points for 10,000 tonnes.
30-40 trap points for 20,000 tonnes.
40-50 trap points for 30,000 tonnes and above.

2) Around the store: use bait bags and place around the store, where accessible and safe, every 5-10 metres.

BAIT BAGS: these are to be used once only throughout the exercise. They should be placed away from rodent runs and, if possible, out of sight of the store staff. Tie through the holes in the bag onto a bamboo cane when used on the grain. Used bags should be emptied and the mesh returned to Slough for refilling.

PITFALL TRAPS: these will need to be fluoned around the top, and old traps will need to be re-fluoned. They should be used only where the grain is not too steeply sloping. They are most effective when placed on small mounds of grain (any slightly raised area) found on the grain surface. <u>ENSURE THAT THE TRAP RIM IS FLUSH WITH THE GRAIN SURFACE</u> and do not worry if a few grains fall into the trap. Place away from walkways and tie round the lower section of the trap and then to a marker cane. Explain the importance of not disturbing the traps to the storekeeper.

INSECT PROBE TRAPS: all probe traps should be inspected on receipt as some may be difficult or impossible to open. Ensure that the collection tubes have a coating of fluon. The traps are pushed vertically into the grain so that the top of the trap is just below the surface of the grain. Each trap must be tied by string to a marker cane.

NOTE: traps have been allocated to each region on a pro rata basis, so that those regions with the most stores will have the most traps. The number of probe traps available is limited so careful planning may be needed and perhaps some exchange between regions once those with a small number of sites have completed their work. The figures given above for number of trapping points, while ideal, may not be achievable with the amount of equipment available.

<u>Inspecting the traps</u>

PLEASE REMEMBER THAT DATA COLLECTION IS ON A STORE, NOT SITE, BASIS: MATERIAL FROM EACH STORE ON A SITE MUST BE LABELLED AND KEPT SEPARATELY.

BAIT BAGS: brief examination of bait bag catches may be needed on site in order to inform the storekeeper of pests present. After examination bait bags and their contents should be placed in labelled polythene bags for examination at base.

PITFALL TRAPS: empty onto a tray and examine the contents for insects and mites. Place the contents in a labelled tube to be examined at base.

PROBE TRAPS: remove from the grain, holding the trap vertically. Snap off the white plug at the base and remove the collection tube. Empty the tube onto a tray and examine for insects and mites. Place the contents in a labelled tube for examination at base. If the probe trap has been used on insecticide-treated grain, wash the trap in soapy water and leave to soak for 24 hours. It will then be necessary, after drying, to re-fluon the collection tube before re-use.

Spread of infestation

It is most important for advisers to minimise the risk of spreading insects and mites from site to site, or from store to store. It may be appropriate to use disposable paper boiler-suits for each visit. These can, of course, be heat sterilised for re-use. These disposable boiler suits are not available from the Slough Laboratory.

Invertebrates to be sent to Slough

Each region will be supplied with:

(a) Clear plastic tubes containing beetle food together with perforated caps and filter paper seals (and spare filter papers).
(b) Opaque polythene tubes with a filter paper wick and containing mite food.
(c) Sealable polythene bags to enclose tubes and contents in case of breakage in the post.
(d) Padded envelopes pre-addressed to Mrs O'Donnell, Slough Laboratory.

Procedure for despatch

PLEASE DESPATCH MATERIAL FROM EACH STORE AT EACH SITE SEPARATELY

PLEASE TRY TO ENSURE THAT ALL MATERIAL ARRIVES ALIVE

1) Beetles: all the species listed on p.15 of the fact sheet are to be sent to Slough. *O. surinamensis*, *Cryptolestes* spp., *Sitophilus* spp., *Tribolium* spp., and *R. dominica* are required for resistance testing. Please collect as many specimens of these species as possible. Wherever possible please sort *O. surinamensis* and *Cryptolestes* spp. from the other species and send separately.

(i) Place the beetles in one of the clear plastic tubes, but do not overcrowd the tubes. Put no more than 150 *Oryzaephilus/Cryptolestes* or 50 of the other species in a single tube. If there are larger numbers then use more than one tube.

(ii) Put the black filter paper in place before replacing the polythene cap - do not attempt a combined operation. Should the filter paper tear, or already be torn, then use a spare paper. Place the paper on top of the tube and fold to the shape of the tube before carefully putting on the cap.

(iii) Label each tube with both the site reference number and the store inspection number and place the tube inside the polythene bag before putting both bag and tube inside the padded envelope provided (only one tube in each envelope please). Enclose a completed tear-off strip from the fact sheet inside each envelope, seal the envelope and post 'first class'.

2) Moths: adults and larvae are required for final identification, please enclose the specimens in one of the clear plastic tubes and follow the procedure in 1 (ii) & (iii) above.

3) Mites and Psocids: A significant proportion of the material collected during the farm survey was ' dead on arrival' at Slough; drowning appeared to be the most common reason for death. Please do not over-moisten the filter paper wicks.

(i) Remove any large debris from the sample and try to exclude predatory mites such as *Cheyletus* spp.

(ii) Open the opaque tube and moisten the filter paper wick with one drop of water.

(iii) Mites - put up to 0.1g of mites (sufficient to be taken up on the tip of a fine spatula) into the tube and close. Psocids - put all the psocids into the tube and close. Use one tube for mites and one tube for psocids.

(iv) Label each tube with the site reference number and store inspection number and place the tube inside the polythene bag, before putting both bag and tube inside the padded envelope provided (only one tube in each envelope please). Enclose a completed tear-off strip from the fact sheet inside each envelope, seal the envelope and post 'first class'. The mite and psocid envelopes are marked with an 'M' so that they can be separated on arrival at Slough.

4) General points: DO NOT mail specimens on a Friday, put them in the tubes and leave in a cool place until the following Monday. Tubes left over the weekend should be aired before posting.

BUT PLEASE send all material as soon as possible after collection, remember we must have them alive!

DO use the padded envelope provided, they have been marked so that they can be identified and taken directly to the quarantine facilities on arrival at Slough.