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OPTIMISATION AND VALIDATION OF A FLOOR TRAP FOR THE DETECTION OF INSECT PESTS IN EMPTY STORES, IN BAGGED STACKS AND ON FLAT SURFACES IN THE CEREAL AND FOOD TRADES

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by

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Contents

Abstract

The aim of the research reported here was to develop and assess a trap to monitor the principal crawling beetle pests of stored products in empty premises, in bagged stacks and on flat surfaces in grain stores and flour mills in the UK.

The study started by testing different monitoring devices in laboratory arenas. In these tests, a CSL prototype trap derived from the CSL pitfall cone trap was compared with the Igrox Insect Monitoring Peanut-free Bait Bag, the Storgard® Flit-Trak M^2 trap and the newly introduced Pantry Patrol™ trap. The beetles tested were six species chosen either because of their important pest status or because they might be difficult to trap. The Pantry Patrol trap gave surprisingly poor results and was therefore not considered further. The CSL prototype trap containing a carob lure was as good as, or better than, the Flit-Trak M^2 trap containing both food oil and pheromone lures in catching *Oryzaephilus mercator*, *Typhaea stercorea*, *Tribolium confusum* and *Cryptolestes ferrugineus*. The CSL prototype trap containing a carob lure and the Flit-Trak food oil was as good as the Flit-Trak M^2 trap in catching the other two species tested, *Sitophilus granarius* and *Rhyzopertha dominica*.

Comparisons were then made between traps in a grain store, in a flour mill and in some laboratory rooms. These tests demonstrated that the CSL prototype trap containing the carob lure and the Flit-Trak food oil was capable of catching the following additional insects: *Oryzaephilus surinamensis*, *Tribolium castaneum*, *Lasioderma serricorne* and psocids. They suggest that this trap was at least as good as the Flit-Trak M^2 trap. The CSL prototype trap has the significant advantage over the Bait Bag that it does not contain food which might, if neglected, act as a source of sustenance for pests and therefore possible re-infestation. Of the traps tested, the CSL prototype trap is the only one which is sturdy, reusable, easy to assemble and leaves the catch easy to identify. For these practical reasons, combined with its proven effectiveness in trapping the above important species, the CSL prototype trap containing a carob lure and the Flit-Trak food oil lure was considered to be the most effective trap.

The CSL prototype trap can, in its present form, contribute usefully to integrated pest management programs by allowing users to get early warning of infestations and demonstrate the effectiveness of the appropriate avoiding action. It is proposed that future work should include simplification of the lure. Then companies to manufacture and market the trap should be identified and an information leaflet written to describe the trap and include guidelines for its use.

Summary

To maintain the quality of post-harvest cereals it is essential to detect pest infestations as early as possible. Early detection would permit control strategies to be devised which reduce the use of persistent contact insecticides and consequently reduce the risk of contamination of food and the environment. The ability to detect insect infestations in empty stores after cleaning would also give an indication of the effectiveness of the cleaning process at removing residual populations of stored commodity insect pests, or indeed whether a residual pesticide treatment is even necessary.

The ideal monitoring trap for use in structures would be inexpensive, re-usable, sturdy, easy to use, and be free from oil and food baits which are potential stored commodity contaminants. Currently, commercially available floor traps do not fulfil these requirements. The bait in 'bait bags' (Pinniger and Wildey, 1979) is not completely contained, it may also be a refuge for feeding and breeding pests, and the pests themselves are not contained. The Storgard® Flit-Trak M² (Fisher *et al.*, 1993; US Patent 5,090,153) contains oil which could contaminate stored commodity or constitute a slip-hazard if it is spilled. The Trappit® *Tribolium* Trap, Agrisense® Insect Monitoring Trap and Russell Environmental Products Safestore™ Trap are not re-usable. Insects tend to gather under rather than in these types of traps and, when they do enter the traps, they are difficult to identify.

A prototype trap with a flat base has been developed at CSL which is cost-effective, re-usable, sturdy, easy to use and which allows easy identification of insects because it does not rely on oil or sticky surfaces to trap them. The CSL prototype trap was based on technology developed in the design and production of the Pitfall Cone (PC) trap. The PC trap was developed with the help of HGCA funding (Pinniger *et al.*, 1990) to meet the need for improved insect monitoring in stored commodities (Anon., 1995; Cogan *et. al.*, 1990). It has been shown to be at least as effective as other trap designs but with the advantage of cheapness and the ability to trap insects both on and below the surface of stored commodities (Cogan and Wakefield, 1994).

The aim of the work reported here was to develop and assess a trap which would:

a) detect and monitor the principal crawling beetle pests of stored products in empty premises, bagged stacks and on flat surfaces in grain stores and flour mills in the UK,
b) do so with an effectiveness which is at least as good as existing traps
c) meet all the criteria for ease of use and low cost
d) allow users to get early warning of infestations and take appropriate avoiding action.

The research started with tests in laboratory arenas of different monitoring devices to trap the following six beetle species: *Tribolium confusum, Sitophilus granarius, Oryzaephilus mercator, Cryptolestes ferrugineus, Rhyzopertha dominica* and *Typhaea stercorea*. The monitoring devices compared were the Igrox Insect Monitoring Peanut-free Bait Bag, the Pantry Patrol™ trap, the Storgard® Flit-Trak M² trap, and the CSL prototype trap. All these were tested with the attractant lures with which they are normally supplied. The most promising traps were then compared in

two week preliminary trials in three types of premises: a grain store, a flour mill and some laboratory rooms.

The results of the laboratory comparisons of the traps showed that the CSL prototype trap with the carob lure alone was significantly better than the Pantry Patrol trap in catching all of the species tested other than *S. granarius.* These disappointing results for the Pantry Patrol trap were surprising given its introduction being so recent, and in consequence its use was not considered further.

The CSL prototype trap with carob lure alone was significantly better than the Flit-Trak M^2 trap in detecting *O. mercator* and *T. stercorea* and it was as good as the Flit-Trak M^2 trap in detecting *T. confusum* and *C. ferrugineus*. The catch of *S. granarius* in the CSL prototype trap was as good as in the Flit-Trak M^2 trap when the former contained a mixture of the carob lure and the food oil from the Flit-Trak M^2 trap. Similarly, the catch of *R. dominica* in the CSL prototype trap was as good with the mixture of carob and Flit-Trak food oil as it was when using the Dominicalure pheromone for this species. The fact that the CSL prototype trap with the combined carob and Flit-Trak lures was as good as the Flit-Trak M^2 trap itself for both *S. granarius* and *R. dominica* suggests that it is the trap of choice.

The results of the premises trial in the grain store showed that the CSL prototype trap was at least as good as the Flit-Trak M^2 trap and the Bait Bag in pinpointing infestations of *O. surinamensis* and *S. granarius* (from the number of positive traps) although the Bait Bag seemed rather better at pinpointing psocids. In terms of numbers of insects caught, the CSL prototype trap was as good as the Flit-Trak M^2 trap but not as good as the Bait Bag for catching *O. surinamensis.* With *S. granarius,* the CSL prototype trap was as good as both the Flit-Trak M^2 trap and the Bait Bag, although in all cases the numbers of insects were very small.

In the flour mill, the CSL prototype trap was better than the Flit-Trak M^2 trap in terms of species and numbers caught and positive traps. The Flit-Trak M^2 trap detected only *T. castaneum* whereas the CSL prototype trap detected *T. castaneum*, *S. granarius* and *O. surinamensis.*

In the laboratory rooms, the CSL prototype trap detected *L. serricorne, O. surinamensis* and psocids. *L. serricorne* and *O. surinamensis* were each detected in one room by the CSL prototype trap but not by the Bait Bag.

For use in flour mills, the CSL prototype trap has the further significant advantage that it does not depend on a sticky surface: sticky traps are currently used in flour mills but are often rendered ineffective by the dusty conditions. This conclusion is further supported by the practical reason that of all those tested, the CSL prototype trap is the only one which is sturdy, reusable, easy to assemble and leaves the catch easy to identify.

It is proposed that future work should include simplification of the lure to aid quality control. Then it would be necessary to identify companies to manufacture and market the trap. An information leaflet describing the trap should be written. This would include guidelines for its use.

INTRODUCTION

To maintain the quality of post-harvest cereals it is essential to detect pest infestations as early as possible. Early detection would permit control strategies to be devised which reduce the use of persistent contact insecticides and consequently reduce the risk of contamination of food and the environment. The ability to detect insect infestations in empty stores after cleaning would also give an indication of the effectiveness of the cleaning process at removing residual populations of stored commodity insect pests, or indeed whether a residual pesticide treatment is even necessary.

It is important to have a monitoring trap for early detection of crawling pests suitable for use in bagged stacks, in empty premises and on flat surfaces throughout the food trade. These premises include farm grain stores, commercial grain stores and flour mills. Early detection of pests is particularly important due to the phasing out of the use of methyl bromide as a control measure, and there is a strong need to develop proactive pest management systems for use in flour mills, based on monitoring pest populations using an efficient monitoring trap.

The ideal monitoring trap for use in structures would be inexpensive, re-usable, sturdy, easy to use, and be free from oil and food baits which are potential stored commodity contaminants. Currently, commercially available floor traps do not fulfil these requirements. The bait in 'bait bags' (Pinniger and Wildey, 1979) is not completely contained, it may also be a refuge for feeding and breeding pests, and the pests themselves are not contained. The Storgard® Flit-Trak M² (Fisher *et al.*, 1993; US Patent 5,090,153) contains oil which could contaminate stored commodity or constitute a slip-hazard if it is spilled. The Trappit® *Tribolium* Trap, Agrisense® Insect Monitoring Trap and Russell Environmental Products Safestore™ Trap are not re-usable. Insects tend to gather under rather than in these types of traps and, when they do enter the traps, they are difficult to identify.

A prototype trap with a flat base has been developed at CSL which is cost-effective, re-usable, sturdy, easy to use and which allows easy identification of insects because it does not rely on oil or sticky surfaces to trap them. The CSL prototype trap was based on technology developed in the design and production of the Pitfall Cone (PC) trap. The PC trap was developed with the help of HGCA funding (Pinniger *et al.*, 1990) to meet the need for improved insect monitoring in stored commodities (Anon., 1995; Cogan *et. al.*, 1990). It has been shown to be at least as effective as other trap designs but with the advantage of cheapness and the ability to trap insects both on and below the surface of stored commodities (Cogan and Wakefield, 1994).

Preliminary laboratory tests have shown that the CSL prototype trap has potential for detecting some of the major grain store pests found in the UK (Clarke 1995, unpublished data). It is now necessary to optimise the floor trap such that it can be used to detect the presence of a range of stored product insect pests.

It may also be possible to increase the effectiveness of the floor trap by augmentation with a lure. Augmentation of the PC trap with a pheromone lure has been very successful with an increase trap catch in excess of ten-fold over unbaited PC traps (Chambers, 1997). Carob volatiles are multi-species attractants (Chambers, 1987) and therefore might constitute a lure for use in a floor trap designed to detect several insect species. Additionally, HGCA funding has been used to establish a method to isolate such volatiles on a useful scale (Pinniger *et al.,* 1990).

The floor trap would be used not only to detect the presence of insects; information gathered would contribute to an overall integrated pest management strategy. Floor trap information could be used in conjunction with decision support software such as the Integrated Grain Store Manager (IGSM) developed by Central Science Laboratory and Imperial College, with support from the HGCA.

The aim of the work reported here was to complete the development and assessment of a trap which would:

a) be able to detect and monitor the presence of the principal crawling beetle pests of stored products which might be found in empty premises, bagged stacks and on flat surfaces in grain stores and flour mills in the UK,
b) do so with an effectiveness which is at least as good as existing traps
c) meet all the criteria for ease of use and low cost
d) allow users to get early warning of infestations and take appropriate avoiding action.

METHODS

Insects

Adult insects of the following species, strains and ages were tested: *Tribolium confusum* lab. susc., 2-4 week old; *Sitophilus granarius* Windsor, 2-4 week old; *Oryzaephilus mercator* lab. susc., 0-2 week old; *Cryptolestes ferrugineus* C124, 0-2 week old; *Rhyzopertha dominica* Salisbury, 2-4 week old; *Typhaea stercorea* Datchet, 2-4 week old. All of the above species were reared in the dark at 25°C and 70% rh, except *C. ferrugineus* which was reared in the dark at 30°C and 70% rh. *S. granarius* and *R. dominica* were fed whole wheat. *T. confusum* was fed whole-wheat flour (ground from heat-treated wheat) and dried de-bittered brewer's yeast mixed 20:1. *O. mercator* and *C. ferrugineus* were fed wheatfeed, rolled oats and dried de-bittered brewer's yeast mixed 5:5:1. *T. stercorea* was fed wheatfeed and dried de-bittered brewer's yeast mixed 10:1.

Traps

- Igrox Insect Monitoring Peanut-free Bait Bag, which was manufactured and supplied by Igrox Ltd and contains carob, wheat and maize (Figure 1a).
- Pantry Patrol™ trap, which was manufactured and supplied by Insects Ltd, and contains sex pheromones for *Plodia interpunctella, Ephestia kuehniella, E. cautella, L. serricorne, Trogoderma variabile,* and *T. granarium* and aggregation pheromones for *T. castaneum* and *T. confusum* incorporated into food oils (Figure 1b).
- Storgard® Flit-Trak M², which was manufactured by Trécé Inc. and supplied by Barrettine Products Ltd and contains a food oil lure and a *Tribolium* pheromone lure (Figure 1c).
- CSL prototype trap - contains 70 µl carob aeration extract A55 encapsulated in a 50 mm long polyethylene tube with heat-sealed ends (Figure 1d).

The traps were tested with their lures as supplied unless otherwise stated. The trap catches were assessed by counting the numbers of insects in the traps, on the traps and under the traps as follows:

An insect was counted as being IN the trap if it was in that part of the trap from which it should not have been able to escape: inside the CSL prototype Floor Trap or in the oil in the Flit-Trak and Pantry Patrol traps. Insects in or on any part of the Bait Bag were counted as in the trap since these are the insects available for counting and identification in normal usage of the Bait Bag. The insects were removed from the Bait Bags by shaking them over a tray. The original formulation Bait Bags which were used in one test were also cut open after shaking because it was observed that some insects were not dislodged by shaking due to the smaller mesh size used to manufacture these Bait Bags.

An insect was counted as being UNDER the trap if it was attached to the underside of the trap when the trap was picked up or the insect was left on the area of the substrate from which the trap had been removed. An insect was counted as being under the Bait Bag only if it was left on area of the substrate from which the trap had been removed.

An insect was counted as being ON the trap if it was on any part of the trap other than the part from which it should not have been able to escape, e.g. the outside of the lid of the CSL prototype Floor Trap, the card cover of the Flit-Trak trap or the exterior sides of the Pantry Patrol trap. No insects were counted as being on the Bait Bags because these were counted as part of the catch in the Bait Bag.

Laboratory arena tests

1. Comparison of different trap types
The CSL prototype trap was compared with the Flit-Trak M^2 trap, the Pantry Patrol trap and the Bait Bag by testing in laboratory arenas. For each species, 1000 insects were divided into batches of 100 and acclimatised to test conditions (20°C, 60% r.h., continuous darkness) overnight along with ten arenas. Each arena was $0.50m^2$ and 0.05m deep, constructed from formica covered chipboard and covered with a transparent acrylic lid. The insides of the walls of the arenas were coated with fluon to prevent the insects from climbing out. One trap was placed in one corner of each arena and 100 conspecific insects were placed in the centre of each arena. The arenas with different trap types were arranged in the test room according to a Latin Squares design. After 24 h, the numbers of insects in, on and under the traps were counted. For the Bait Bag, the numbers of insects found on the bag were combined with those found within it since it is not a true trap. Five replicates were carried out for each species with each trap type. The data obtained were square root transformed and compared using Anova followed by Newman-Keuls multiple comparisons test (Sokal & Rolf, 1969), where necessary.

2. Comparison of different hole sizes in the lid of the CSL prototype trap
It was concluded from preliminary tests, with *S. granarius* in glass tubes with holes of different sizes (2.2, 2.4, 2.6, 2.8 and 3.0 mm dia.) drilled in their plastic lids, that increasing the size of the holes to 2.8 mm dia. might increase the trap catch of this species. Five replicates with the original hole size (2.0 mm dia.) and five replicates

with 2.8 mm dia. were tested with *S. granarius* using the same method and conditions as in section 1 above. For these experiments, the numbers of insects and in and on (*i.e.* not under) the traps were recorded. All the traps contained the carob lure.

3. Comparison of lures with *S. granarius* and *R. dominica*
To ascertain whether a different lure would increase the catches of *S. granarius* and *R. dominica* by the CSL prototype trap, the following comparisons were made using the same method and conditions as in section 1 above. For experiments a) and b) the numbers of insects counted were simply those in the traps. For experiment c), the numbers counted were those in and on the traps.

a) With *S. granarius*, a carob lure alone (as described above) was compared with a carob lure together with 280mg of sitophinone in 70 μl of pentane (lure construction as for carob lure). The sitophinone was synthesised by Gareth Bryning, CSL, and 99.9% pure.

b) With *R. dominica*, a carob lure alone was compared with a carob lure and 1mg of dominicalure (lure construction as for carob lure). The dominicalure (components (S)-(+)-1-methylbutyl (E)-2-methyl-2-pentenoate and (S)-(+)-1-methylbutyl (E)-2,4-dimethyl-2-pentenoate) was supplied by Dudley Farman NRI.

c) With both *S. granarius* and *R. dominica*, 1 ml of the Flit-Trak food oil lure was placed in a weighing boat in each of five CSL prototype traps with the carob lure. The trap catches of *S. granarius* and *R. dominica* in these traps were compared with the trap catches of five CSL prototype traps with carob lures. These were also compared against five Flit-Trak M^2 traps with both food and pheromone lures as supplied.

Premises tests

Each of the following tests was carried out over a two week period. Traps were replaced and trap catches in but not on or under the traps counted at the end of each week. The Pantry Patrol Trap was not included in field tests due to its poor performance in laboratory tests. Temperature and humidity were recorded continuously using Tinytalk® II dataloggers.

Grain store
The traps used were the peanut-free Bait Bag, the Flit-Trak M^2 with lures as supplied and the CSL prototype trap with carob lure and Flit-Trak food oil lure. Ten traps of each type were placed at various positions around the perimeter of Flat Store 2 of the grain store at CSL York (Figure 2). At the time of this test, the flat store was occupied by wheat. The test started on 8 March 2000.

Flour mill
Ten traps of each type were placed at various positions around a flour mill in North Yorkshire (Figure 3). The traps used were the Flit-Trak M^2 with lures as supplied and the CSL prototype trap with carob lure and Flit-Trak food oil lure. The Peanut-free Bait Bag was excluded from this test due to concerns of the flour mill quality

assurance manager about possible contamination, particularly possible contamination with genetically modified maize. This test started on 18 February 2000.

Laboratory rooms at CSL

Two traps of each type (CSL prototype trap and Bait Bag, manufactured by Igrox Ltd and supplied by Agricultural Services and Supplies, which contained carob, peanuts and wheat) were placed in each of five laboratory rooms suspected to be infested with escaped insects. The CSL prototype trap was used with a carob lure and the oil lure from the Flit-Trak M^2 trap. The traps were placed in pairs of one of each type and left for 14 days. The distance between traps within each pair was 15 cm. The insects in each trap were identified and counted.

RESULTS

Laboratory arena tests

1. Comparison of different trap types

The numbers of insects found in the traps are shown in Figure 4. There were statistically significant differences between the numbers of each of the species caught in the different trap types (for each species: $n = 5$ for each trap type, $p < 0.01$), although the mean catches of the different types of trap varied for each species. The numbers of insects found either on or under the traps are shown in Figure 5. There were also statistically significant differences between the numbers of each of the species observed on the different trap types (for each species: $n = 5$ in each case, $p < 0.01$), although the mean numbers of insects on the different types of trap varied for each species.

O. mercator

Significantly more *O. mercator* were caught in the CSL prototype trap (81.0%) than in the Flit-Trak M^2 (51.1%) or Pantry traps (8.4%). There was no significant difference between the number of *O. mercator* caught in the CSL prototype trap and the Bait Bag (67.2%) or between the number of *O. mercator* caught in the Flit-Trak M^2 trap and the Bait Bag. Significantly fewer *O. mercator* were caught in the Pantry trap than in any of the other trap types (Figure 4a). *O. mercator* were observed walking down the inner wall of the Pantry trap and then turning and walking back out of the trap again. Significantly fewer *O. mercator* were observed on the CSL prototype trap than on the other two trap types. Significantly more *O. mercator* were observed under the Pantry trap than under any other trap type except the Bait Bag ($p = 0.022$) (Figure 5a).

T. confusum

There was no significant difference between the number of *T. confusum* caught in the CSL prototype trap (44.6%) and the Flit-Trak M^2 trap (37.5%) or between the CSL prototype trap and Bait Bag (55.7%). Significantly fewer *T. confusum* were caught in the Pantry trap (24.0%) than in any of the other trap types (Figure 4b). Significantly more *T. confusum* were observed on the Flit-Trak M^2 trap than on the Pantry Trap, and on the Pantry Trap than on the CSL prototype trap. A large number of *T. confusum* gathered between the plastic and card parts of the Flit-Trak M^2 trap and on the outside of the Pantry trap at the right-angled corner where the vertical sides meet the horizontal edge at the bottom of the trap (Figure 5b).

T. stercorea

Significantly more *T. stercorea* were caught in the CSL prototype trap (87.4%) than in any of the other trap types. There was no significant difference between the number of *T. stercorea* caught in the Flit-Trak M^2 trap (31.1%) and the Bait Bag (59.5%). Significantly fewer *T. stercorea* were caught in the Pantry trap (2.9%) than in any of the other trap types (Figure 4c). *T. stercorea* were observed climbing out of the oil in the Pantry trap and they also gathered on the outside of the trap at the right-angled corner where the vertical sides meet the horizontal edge at the bottom of the trap. Significantly more *T. stercorea* were observed on the Pantry trap than on the Flit-Trak M^2 trap and none were observed on the CSL prototype trap.

S. granarius

Significantly more *S. granarius* were caught in the Flit-Trak M^2 trap (99.2%) and the Bait Bag (92.0%) than in the CSL prototype (50.2%) and Pantry traps (66.6%). Significantly fewer *S. granarius* were caught in the CSL prototype trap than in any other trap type (Figure 4d.) Significantly more *S. granarius* were observed on the CSL prototype trap than on the Pantry trap and none were observed on the Flit-Trak M^2 trap. There were no *S. granarius* observed under any of the traps (figure 5d). The *S. granarius* on the CSL prototype trap were observed to hold onto the sides of the holes with their legs, thus avoiding falling into the trap. They were also observed walking down the inner wall of the Pantry trap then turning round and walking back out of the trap and escaping from the oil in the Pantry trap.

R. dominica

Significantly more *R. dominica* were caught in the Flit-Trak M^2 trap (51.5%) and the Bait Bag (65.9%) than in the CSL prototype (21.1%) and Pantry traps (7.3%). Significantly fewer *R. dominica* were caught in the Pantry trap than in any of the other trap types (Figure 4e). Significantly more *R. dominica* were observed on the Flit-Trak M^2 trap than on the CSL prototype trap or the Pantry trap. Significantly more *R. dominica* were observed under the Pantry Trap than under any other trap type. Significantly fewer *R. dominica* were observed under the CSL prototype trap than under and other trap type ($p < 0.01$) (Figure 5e). *R. dominica* were also observed to escape from the oil in the Pantry trap.

C. ferrugineus

There was no significant difference between the number of *C. ferrugineus* caught in the CSL prototype trap (45.1%) and the Flit-Trak M^2 trap (53.8%). Significantly more *C. ferrugineus* were caught in the Bait Bag (81.9%) than in any of the other trap types and significantly fewer *C. ferrugineus* were caught in the Pantry trap (5.4%) than in any of the other trap types (Figure 4f). Significantly more *C. ferrugineus* were observed on the Flit-Trak M^2 trap than on the Pantry trap and none were observed on the CSL prototype trap. There was no significant difference in the number of *C. ferrugineus* observed under any of the trap types (Figure 5f). *C. ferrugineus* were also found between the plastic and card parts of the Flit-Trak M^2 trap and escaped from the oil in the Pantry trap.

2. Comparison of different hole sizes in the lid of the CSL prototype trap
There was no statistically significant difference between the number of insects caught in the CSL prototype traps with different hole sizes (Mann-Whitney U-test, $n = 5$, $p = 0.352$). Neither was there any statistically significant difference between the number of insects observed on the CSL prototype traps with different hole sizes (Mann-Whitney U-test, $n = 5$, $p = 0.214$) (Table 1). Mann-Whitney U-tests were used for these analyses because the variances of the two samples were too different to allow use of a t-test. Even with the larger size of holes, the *S. granarius* were still observed to hold onto the sides of the holes with their legs. It was not possible to drill the holes with a greater diameter without the holes running into each other.

Table 1. *S. granarius* in and on traps with different hole sizes

	***S. granarius* in traps**		***S. granarius* on traps**	
Diameter of hole (mm)	**Derived mean**	**95% Confidence limits**	**Derived mean**	**95% Confidence limits**
2.0	51.8	57.7, 51.7	7.2	9.5, 7.1
2.8	43.3	54.3, 42.7	9.3	11.2, 9.2

3. Comparison of lures with *S. granarius* and *R. dominica*
There was no statistically significant difference between the number of *S. granarius* caught in the CSL prototype traps with the carob lure whether augmented with sitophinone or not (Table 2).

Table 2. *S. granarius* in traps with either carob alone or with carob and sitophinone lures

	***S. granarius* in traps**	
Lure	**Derived mean**	**95% Confidence limits**
carob	67.2	70.6, 67.1
carob + sitophinone	56.8	69.2, 56.1

Significantly more *R. dominica* were caught in the traps with carob and dominicalure than in those with carob alone ($t = 9.00$, $p < 0.001$) (Table 3).

Table 3. *R. dominica* in traps with carob alone with or carob and dominicalures

	***R. dominica* in traps**	
Lure	**Derived mean**	**95% Confidence limits**
carob	20.4	27.9, 19.8
carob + dominicalure	56.8	64.1, 56.5

There was an overall statistically significant difference between the number of *S. granarius* caught in the Flit-Trak M^2 trap and CSL prototype traps with carob or Flit-Trak oil lures ($P < 0.001$, ANOVA, $n = 5$ for each set). The CSL prototype trap with the carob lure caught significantly fewer insects than the other two combinations ($P < 0.05$, Newman-Keuls Multiple Comparisons test), marked with a * in Table 4 below (Figure 6). There was no statistically significant difference between the trap catches in the CSL prototype trap with the Flit-Trak oil lure and the Flit-Trak M^2 trap as supplied.

There was also an overall significant difference between the number of *S. granarius* observed on the traps ($P = 0.003$, ANOVA, $n = 5$ for each set). There were significantly more insects on the CSL prototype trap with the carob lure than on the other two combinations ($P < 0.05$, Newman-Keuls Multiple Comparisons test), marked with a * in table 4 below. There was no statistically significant difference between the numbers of insects observed on the CSL prototype trap with the Flit-Trak oil lure and the Flit-Trak M^2 trap as supplied.

Table 4. Comparison of carob and Flit-Trak oil lures with *S. granarius*

	***S. granarius* in traps**		***S. granarius* on traps**	
Trap	**Derived mean**	**95% Confidence limits**	**Derived mean**	**95% Confidence limits**
CSL prototype with carob lure	45.3 *	64.2, 43.6	2.3 *	5.5, 1.6
CSL prototype with carob and Flit-Trak oil lures	94.6	98.9, 94.5	0.04	0.4, -0.1
Flit-Trak M^2 as supplied	99.2	99.9, 99.2	0	0, 0

There was an overall statistically significant difference between the number of *R. dominica* caught in the Flit-Trak M^2 trap and CSL prototype traps with carob or Flit-Trak oil lures ($P < 0.001$, ANOVA, $n = 5$ for each set). The CSL prototype trap with the carob lure caught significantly fewer insects than the other two combinations ($P < 0.05$, Newman-Keuls Multiple Comparisons test), marked with a * in Table 5 below. There was no statistically significant difference between the trap catches in the CSL prototype trap with Dominicalure, CSL prototype trap with the Flit-Trak oil lure and the Flit-Trak M^2 trap as supplied. Only two insects were observed on these traps during the test so a statistical comparison was not made.

Table 5. Comparison of carob and Flit-Trak oil lures with *R. dominica*

	***R. dominica* in traps**	
Trap	**Derived mean**	**95% Confidence limits**
CSL prototype with carob lure	20.4 *	27.9, 19.8
CSL prototype with carob and Flit-Trak oil lure	50.8	64.2, 50.0
Flit-Trak M^2 as supplied	51.5	56.7, 51.3

Premises tests

Grain store

Temperature and humidity recordings for both weeks are shown in Table 6. There were similar numbers of positive traps (those in which insects were found) of each trap type for *O. surinamensis, S. granarius* and psocids in both sampling weeks (Table 7). In addition, in the first week, CSL prototype traps also caught one histerid beetle and one *Ptinus fur* and Bait Bags caught one staphylinid beetle (*Tachyporus hypnorum*) and one trogositid beetle.

Table 6. Temperature and relative humidity in the grain store

		Week 1 (8/3/00 - 15/3/00)			Week 2 (15/3/00 - 22/3/00)		
Location	**Function**	**Mean**	**Max.**	**Min.**	**Mean**	**Max.**	**Min.**
2	Temperature (°C)	8.2	12.6	3.4	6.9	10.1	1.4
4	Temperature (°C)	8.0	10.4	4.9	7.1	10.1	3.0
7	Temperature (°C)	8.3	12.6	5.6	7.6	9.3	3.4
8	Temperature (°C)	10.7	14.0	6.0	9.8	13.6	3.0
9	Temperature (°C)	8.0	11.5	4.9	6.9	8.6	3.0
10	Temperature (°C)	8.0	10.4	4.9	7.0	10.1	2.6
9	Humidity (% rh)	82	91	51	81	89	67

Table 7. Numbers of positive traps in grain store out of the ten placed

	CSL prototype		Flit-Trak M^2		Bait Bag	
Insect	**Week 1**	**Week 2**	**Week 1**	**Week 2**	**Week 1**	**Week 2**
O. surinamensis	10	10	9	10	10	10
S. granarius	4	4	3	3	3	4
psocids	8	4	7	6	10	8

The numbers of *O. surinamensis* caught in the different trap types were significantly different (Kruskal-Wallis one-way Anova, $p < 0.001$ for both sampling weeks) with more insects caught in the Bait Bag than in the other two trap types in the first week (Newman-Keuls multiple comparisons test, $p < 0.05$). In the second week there was no significant difference between the numbers of *O. surinamensis* caught in the CSL prototype trap and the Bait Bag, or between the CSL prototype trap and the Flit-Trak M^2 trap. Significantly more *O. surinamensis* were caught in the Bait Bag than in the Flit-Trak M^2 trap (Newman-Keuls multiple comparisons test, $p < 0.05$) (Table 8).

There was no significant difference between the numbers of *S. granarius* caught in the different trap types in either of the sampling weeks (Table 9).

Table 8. Numbers of *O. surinamensis* in traps in grain store

	CSL prototype		Flit-Trak M^2		Bait Bag	
Location	**Week 1**	**Week 2**	**Week 1**	**Week 2**	**Week 1**	**Week 2**
1	16	8	11	4	38	28
2	13	22	5	2	20	41
3	7	1	3	5	16	16
4	1	11	0	1	3	2
5	17	30	7	8	31	37
6	6	28	2	6	18	54
7	22	18	22	9	55	47
8	3	5	4	9	34	17
9	4	17	2	21	34	42
10	2	3	2	5	18	19
mean (± 95% c.l.)	9.1 (4.5)	14.3 (6.4)	5.8 (4.0)	7.0 (3.5)	26.7 (9.1)	30.3 (10.2)

Table 9. Numbers of *S. granarius* in traps in grain store

	CSL prototype		Flit-Trak M^2		Bait Bag	
Location	**Week 1**	**Week 2**	**Week 1**	**Week 2**	**Week 1**	**Week 2**
1	1	2	0	1	2	0
2	0	1	1	1	0	1
3	0	0	0	0	0	0
4	0	0	0	1	0	0
5	1	0	1	0	1	1
6	0	0	0	0	2	0
7	1	0	1	0	0	1
8	0	1	0	0	0	0
9	0	0	0	0	2	0
10	2	1	0	0	0	3
mean (± 95% c.l.)	0.5 (0.4)	0.5 (0.4)	0.3 (0.3)	0.3 (0.3)	0.7 (0.6)	0.6 (0.6)

The numbers of psocids caught in the different trap types were significantly different in the first week but not the second week (Kruskal-Wallis one-way Anova, $p = 0.028$, for the first week). In the first week, there was no significant difference between the numbers psocids caught in the CSL prototype trap and the Bait Bag, or between the numbers psocids caught in the CSL prototype trap and the Flit-Trak M^2 trap. Significantly more psocids were caught in the Bait Bag than in the Flit-Trak M^2 trap (Newman-Keuls multiple comparisons test, $p < 0.05$) (Table 10).

Table 10. Numbers of psocids in traps in grain store

Location	CSL prototype		Flit-Trak M^2		Bait Bag	
	Week 1	Week 2	Week 1	Week 2	Week 1	Week 2
1	4	10	4	2	17	4
2	2	0	0	1	7	4
3	1	0	6	4	58	26
4	1	0	0	0	2	0
5	3	20	1	0	20	18
6	5	18	3	1	4	5
7	6	0	4	1	2	0
8	0	0	2	0	6	2
9	3	5	0	0	2	2
10	0	0	3	3	17	3
mean (± 95% c.l.)	2.5 (1.3)	5.3 (4.9)	2.3 (1.3)	1.2 (0.9)	13.5 (10.6)	6.4 (5.3)

Flour mill

Temperature and humidity recordings for both weeks are shown in Table 11. In the first sampling week there was only one positive trap of each type, however in the second week there were four positive CSL prototype traps and only one positive Flit-Trak M^2 trap. The CSL prototype trap caught three species of insects over the two week sampling period whereas the Flit-Trak M^2 trap caught only one species (Table 12).

Table 11. Temperature and relative humidity in the flour mill

Location	Function	Week 1			Week 2		
		Mean	Max.	Min.	Mean	Max.	Min.
Top floor	Temperature (°C)	12.7	17.8	5.6	13.1	16.4	8.6
Separator floor	Temperature (°C)	9.8	15.4	6.0	10.8	14.0	9.0
Sifter floor	Temperature (°C)	11.6	15.7	6.8	12.1	15.0	8.2
Stoner floor	Temperature (°C)	11.0	15.0	6.8	11.7	14.3	9.7
Spout floor	Temperature (°C)	14.3	18.2	9.3	14.8	18.2	10.4
Ground floor	Temperature (°C)	13.4	16.4	11.1	13.8	15.4	12.2
Separator floor	Humidity (% rh)	49	69	36	54	69	40

Table 12. Trap catches in the flour mill

	CSL prototype		Flit-Trak M^2	
Week	Trap no.	Catch	Trap no.	Catch
1	5	3 x *S. granarius*	11	1 x *T. castaneum*
2	7	3 x *T. castaneum*	3	1 x *T. castaneum*
	6	2 x *T. castaneum*		
	8	2 x *S. granarius*		
	10	1 x *S. granarius*, 1 x *O. surinamensis*		

Laboratory rooms at CSL
Three species of beetle (*L. serricorne, O. surinamensis, S. granarius*) and psocids were caught in both types of trap. *L. serricorne* and *O. surinamensis* were each caught in one lab. in the CSL prototype traps but not in the Bait Bags (Table 13).

Table 13. Trap catches in laboratories

	Bait Bag					CSL prototype trap				
	Room					Room				
Species	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
L. serricorne			5	10	2	1		24	4	1
O. surinamensis					3		2			5
S. granarius			8	15	53			10	4	4
psocids					*					~ 650

* Hundreds of psocids were present but they were very difficult to count in the dust from the Bait Bag.

DISCUSSION

The six beetle species tested were chosen either for their significant pest status in the UK (*S. granarius*) or because they are likely to be the most difficult to trap, due to a lack of climbing ability (*O. mercator, C. ferrugineus, T. confusum, R. dominica* and *T. stercorea*). It is necessary that the insects are able to climb up the base of the trap because the trap is of a pitfall design and the entrance holes are, therefore, above ground level. A pitfall trap design is the most effective way to retain insects without using a sticky surface, which might render difficult the identification of a trapped insect and would probably be made ineffective by adsorption of flour in a mill.

The CSL prototype floor trap was tested against three other designs. The Flit-Trak M^2 trap was chosen because it is one of the best stored product beetle traps currently on the market. The Flit-Trak trap is more efficient at catching *T. castaneum* and *S. zeamais* than three other available trap types, including a sticky trap (Fisher *et al.*, 1993). The Pantry patrol trap was chosen because it is one of the most recent additions to the range of traps available for stored product pests (Van Ryckeghem *et al.*, 1999). The developers claim that it is effective for a wide range of species, including those the CSL prototype trap was tested against in this study. The peanut-free Bait Bag was included because it is known to be effective in detecting stored product insects, although it does not necessarily retain insects and might be considered unsuitable in premises where the presence of the food it contains would be unacceptable. The original Bait Bag has been used successfully in farms, mills and warehouses and has been shown to detect a wide range of species (Pinniger 1975). The manufacturers of the peanut-free version of the Bait Bag claim that it is as good as the original version.

The results of the laboratory comparisons of the traps show that the CSL prototype trap with the carob lure alone was significantly better than the Pantry Patrol trap in catching all of the species tested other than *S. granarius*. These disappointing results for the Pantry Patrol trap were surprising given its introduction being so recent, and in consequence its use was not considered further.

The CSL prototype trap with carob lure alone was significantly better than the Flit-Trak M^2 trap in detecting *O. mercator* and *T. stercorea* and it was as good as the Flit-Trak M^2 trap in detecting *T. confusum* and *C. ferrugineus*. The CSL prototype trap was significantly poorer than the Flit-Trak M^2 trap in catching *S. granarius* and *R. dominica*. In the case of the former species, the large number of beetles found on the trap, and the observation that they would hold onto the sides of the holes which would save them from falling into the trap, suggested that the use of larger holes might help. Such behaviour has been noted previously with the parent pitfall-cone trap from which the prototype trap studied here was derived (Wakefield, 1995). However, increasing the hole size from 2.0 mm to the largest practical size (2.8 mm) did not overcome the problem and there was no improvement in trap catch. Surprisingly, no improvement was obtained by adding to the carob food lure, a pheromone lure based on sitophinone. Although this pheromone is not produced by *S. granarius*, in combination with carob it has been shown to increase significantly the catch of this species in the pitfall-cone trap (Wakefield, 1997). Interestingly, the catch of *S. granarius* in the CSL prototype trap was as good as in the Flit-Trak M^2 trap when the former contained a mixture of the carob lure and the food oil from the Flit-Trak M^2 trap. This is not wholly unexpected because the Flit-Trak oil may be derived from a food source to which *S. granarius* is markedly attracted. Similar reasons may explain why the catch of *R. dominica* in the CSL prototype trap was as good with the mixture of carob and Flit-Trak food oil as it was when using the Dominicalure pheromone for this species (Williams *et al.*, 1981). The fact that the CSL prototype trap with the combined carob and Flit-Trak lures was as good as the Flit-Trak M^2 trap itself for both *S. granarius* and *R. dominica* suggests that it is the trap of choice.

The results of the premises trial in the grain store showed that the CSL prototype trap was at least as good as the Flit-Trak M^2 trap and the Bait Bag in pinpointing infestations of *O. surinamensis* and *S. granarius* (from the number of positive traps) although the Bait Bag seemed rather better at pinpointing psocids. In terms of numbers of insects caught, the CSL prototype trap was as good as the Flit-Trak M^2 trap but not as good as the Bait Bag for catching *O. surinamensis.*. With *S. granarius*, the CSL prototype trap was as good as both the Flit-Trak M^2 trap and the Bait Bag, although in all cases the numbers of insects were very small.

In the flour mill, the CSL prototype trap was better than the Flit-Trak M^2 trap in terms of species and numbers caught and positive traps. The Flit-Trak M^2 trap detected only *T. castaneum* whereas the CSL prototype trap detected *T. castaneum, S. granarius* and *O. surinamensis.*

In the laboratory rooms, the CSL prototype trap detected *L. serricorne, O. surinamensis* and psocids. *L. serricorne* and *O. surinamensis* were each detected in one room by the CSL prototype trap but not by the Bait Bag.

CONCLUSIONS

This study has shown that in arena tests in the laboratory, the CSL prototype trap containing a carob lure is as good as, or better than, the Flit-Trak M^2 trap containing both food oil and pheromone lures in catching *O. mercator, T. stercorea, T. confusum* and *C. ferrugineus*. It has also shown that the CSL prototype trap containing a carob lure and the Flit-Trak food oil is as good as the Flit-Trak M^2 trap in catching the other two species tested, *S. granarius* and *R. dominica*.

The tests of the traps in different kinds of premises were limited both in number and duration. They do however demonstrate that the CSL prototype trap containing the carob lure and the Flit-Trak food oil is capable of catching the following additional insects: *O. surinamensis, T. castaneum. Lasioderma serricorne* and psocids. The premises tests suggest that this trap was at least as good as the Flit-Trak trap. In the flour mill, the CSL prototype trap was less good than the Bait Bag at pinpointing infestations of psocids and in numbers of *O. surinamensis* caught but it has the significant advantage over the latter that it does not contain food which might, if neglected, act as a source of sustenance for pests and therefore possible re-infestation. For use in flour mills, the CSL prototype trap has the further significant advantage that it does not depend on a sticky surface: sticky traps are currently used in flour mills but are often rendered ineffective by the dusty conditions (personal communication from a flour mill Quality Assurance Manager).

This conclusion is further supported by the practical reason that of all those tested, the CSL prototype trap is the only one which is sturdy, reusable, easy to assemble and leaves the catch easy to identify.

It is proposed that future work should include simplification of the lure. The carob and Flit-Trak food oil lures used in this study are both natural products and hence it is difficult to ensure that they are of consistent quality. A simplified lure in the form of a blend of inexpensive chemicals would aid quality control and be cheaper to produce. Then it would be necessary to identify companies to manufacture and market the trap. An information leaflet describing the trap should be written. This would include guidelines for its use.

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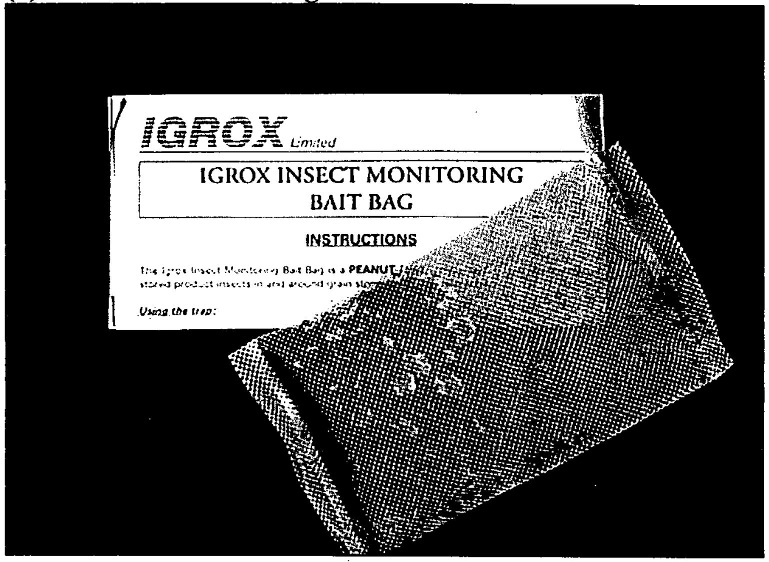
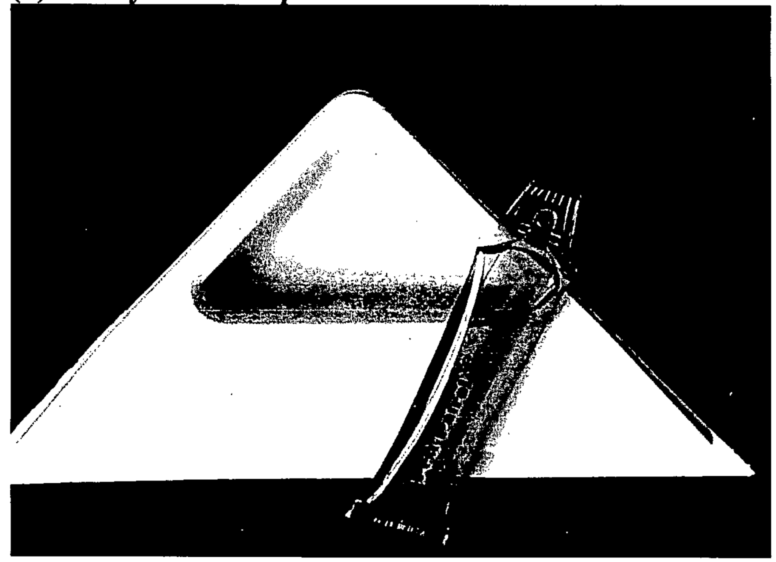
Figure 1. Traps compared in this study

(a) Peanut-free Bait Bag



(b) Pantry Patrol trap



(c) Flit-Trak m^2 trap

(d) CSL prototype trap with carob lure

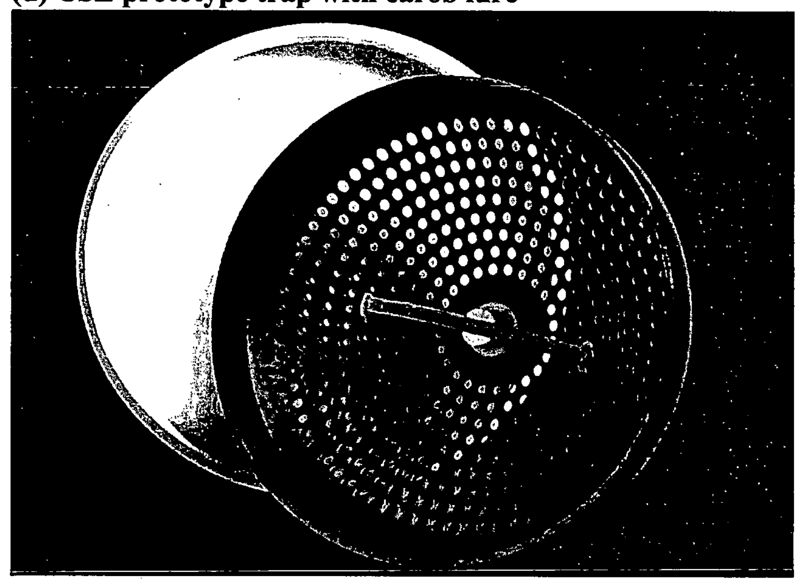


Figure 2. Positions of traps and temperature and humidity data loggers in the grain store.

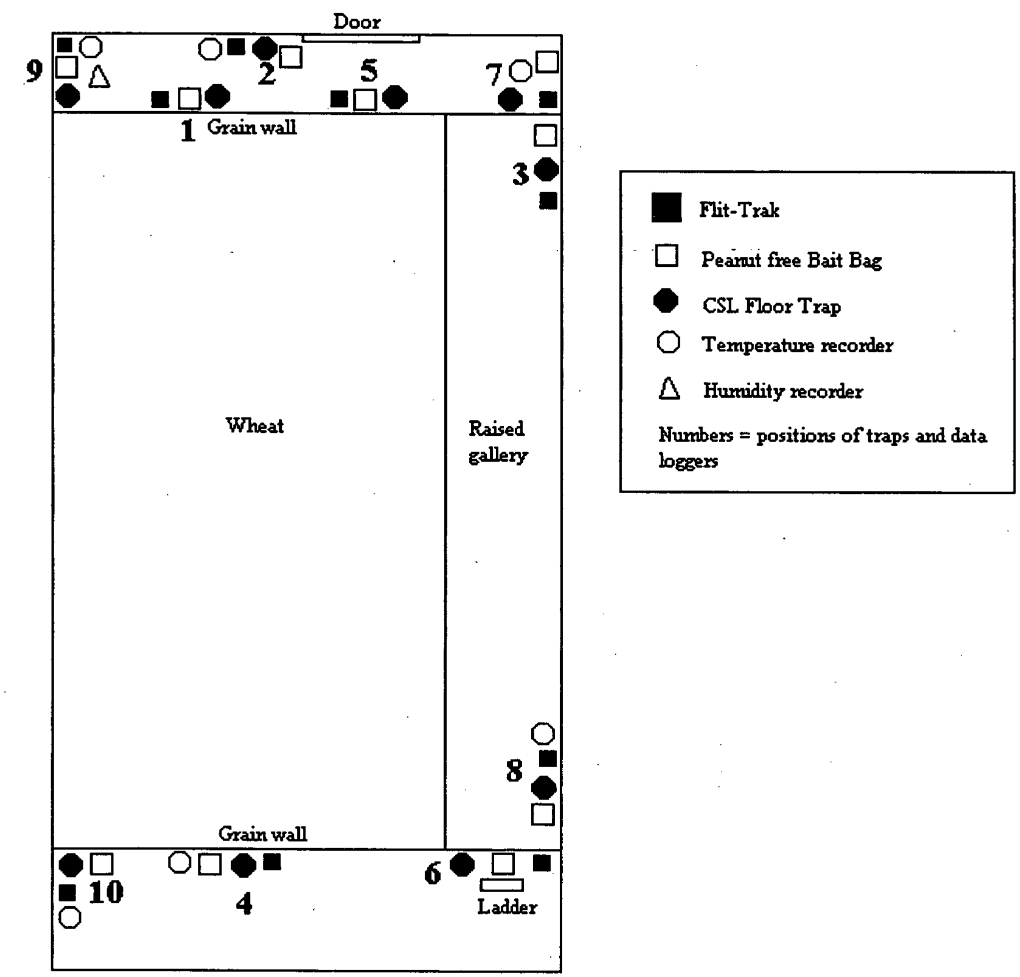
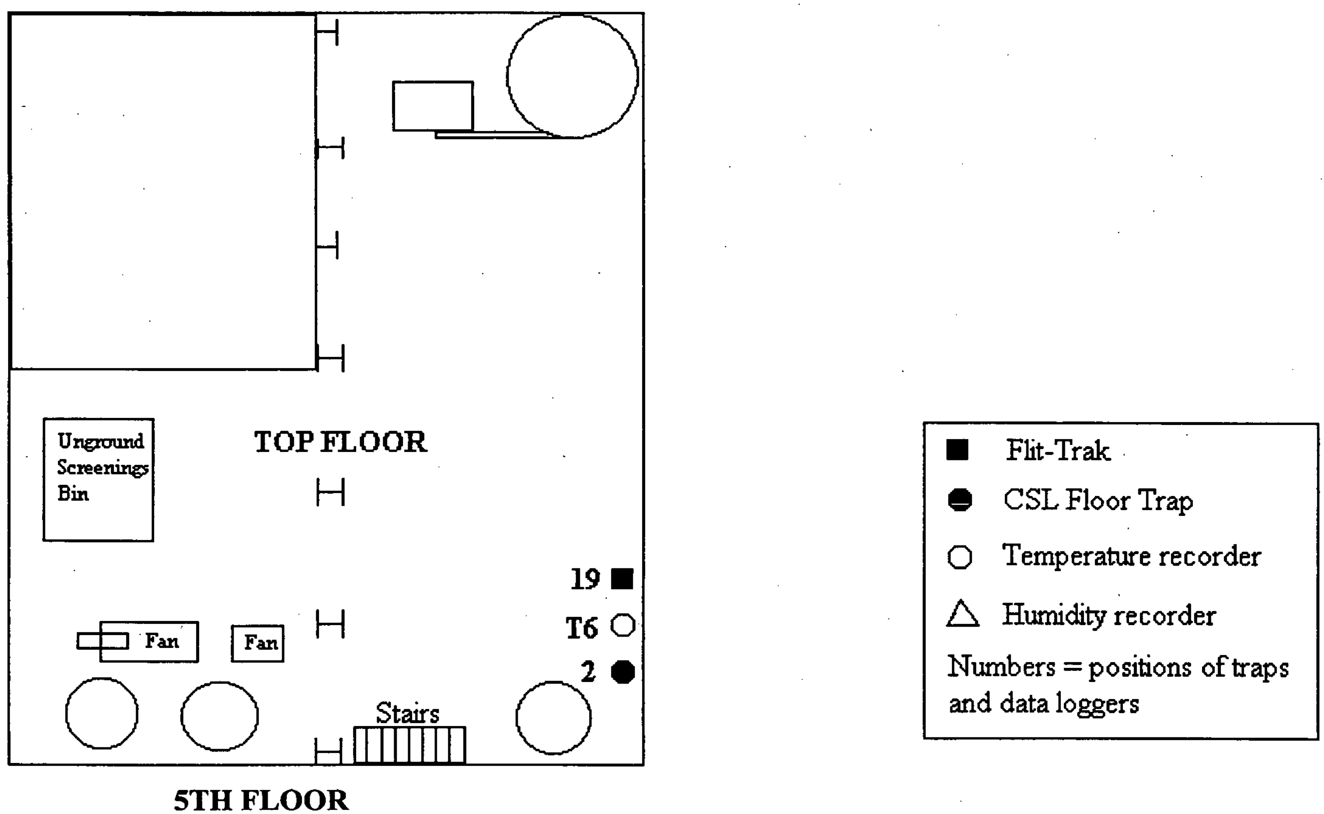
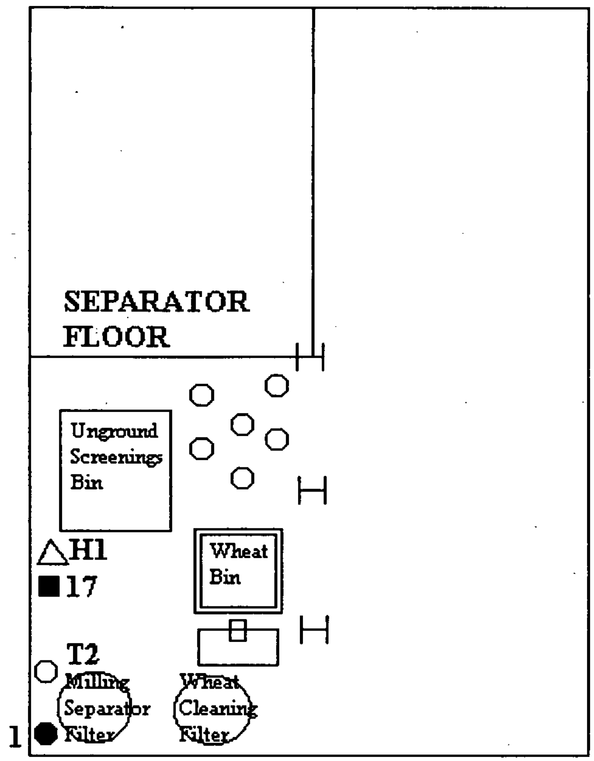
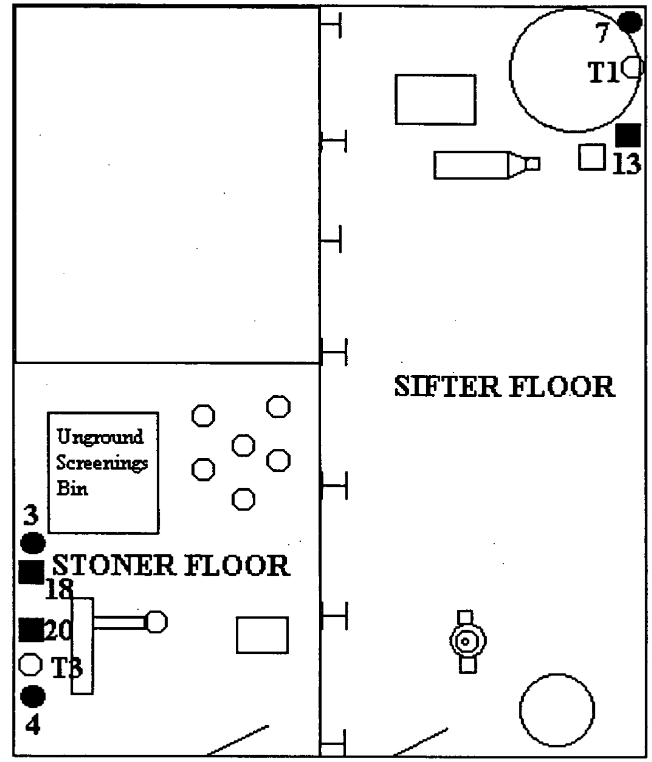


Figure 3. Positions of traps and temperature and humidity data loggers in the flour mill.

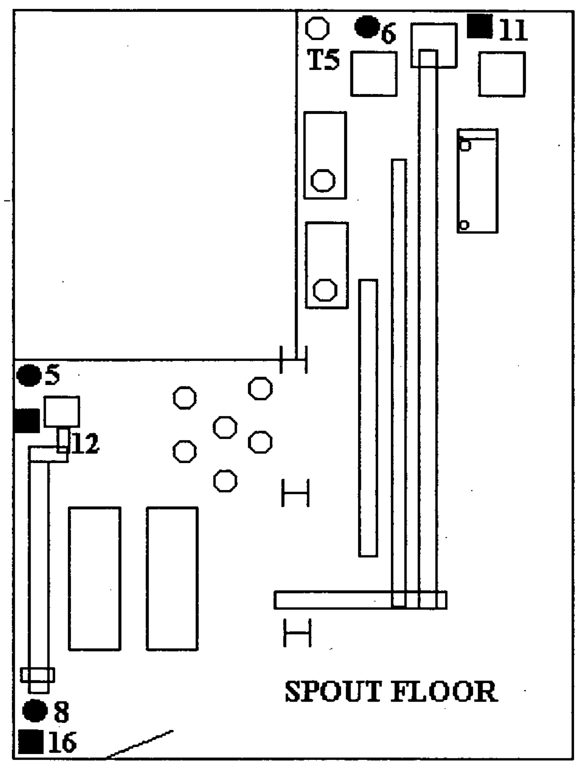




4TH FLOOR



2ND FLOOR 3RD FLOOR



1ST FLOOR

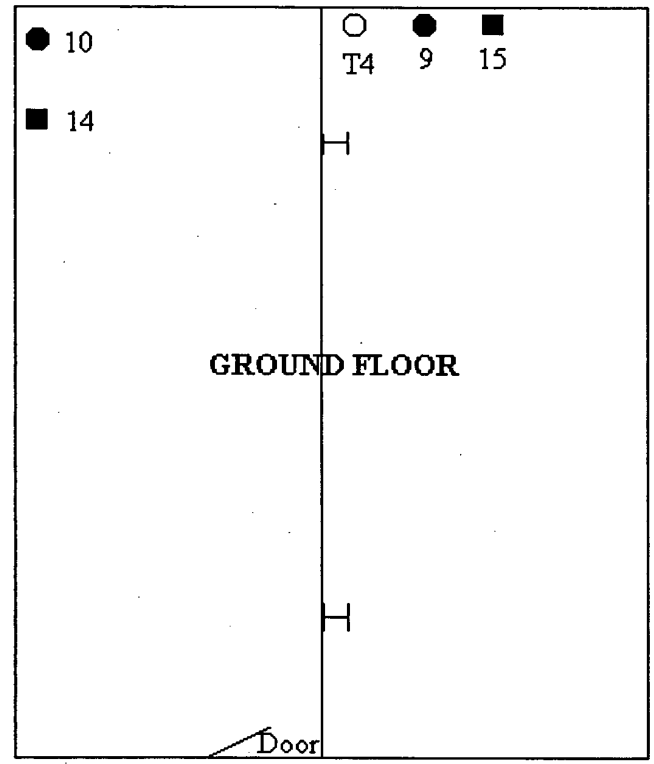
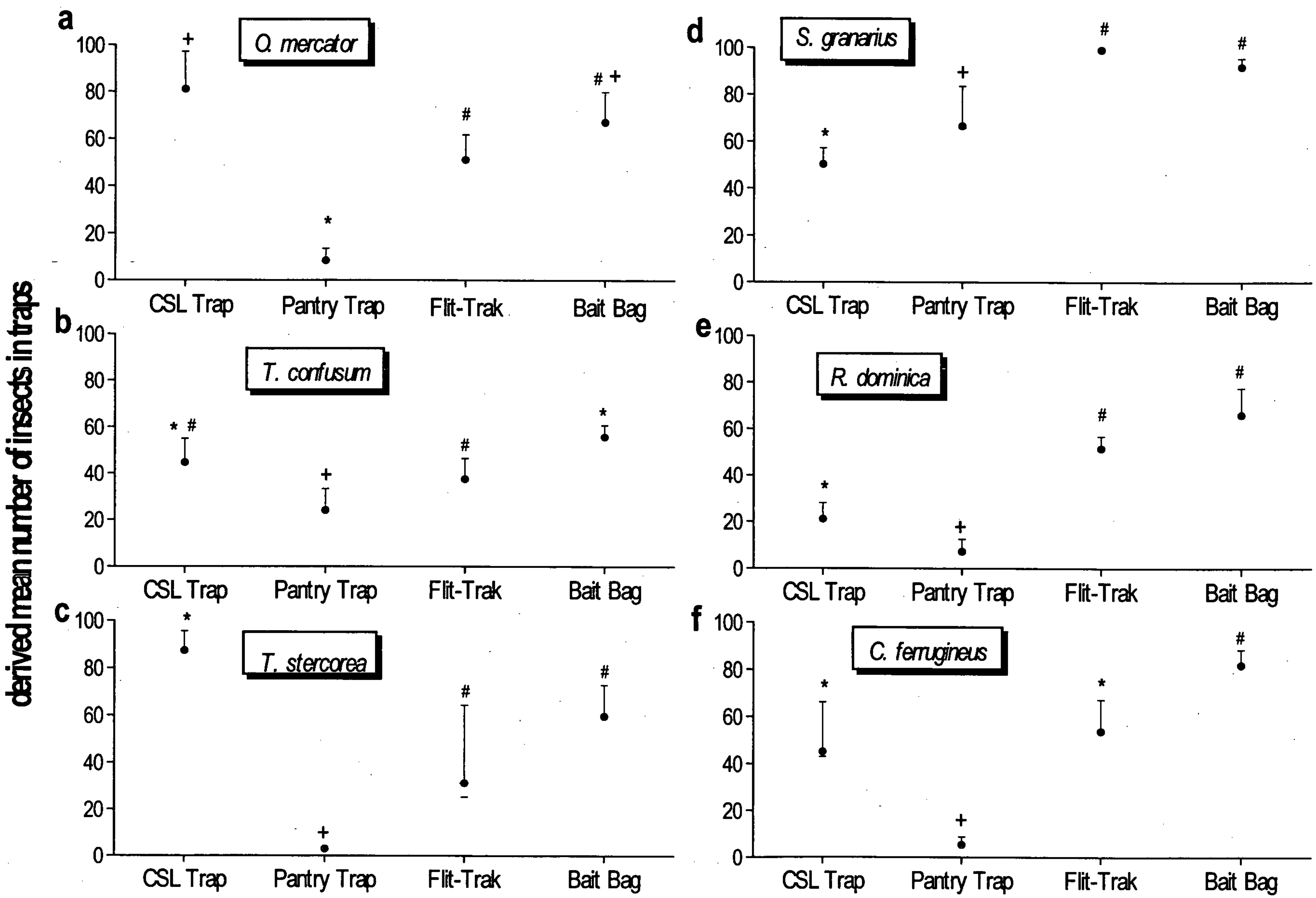
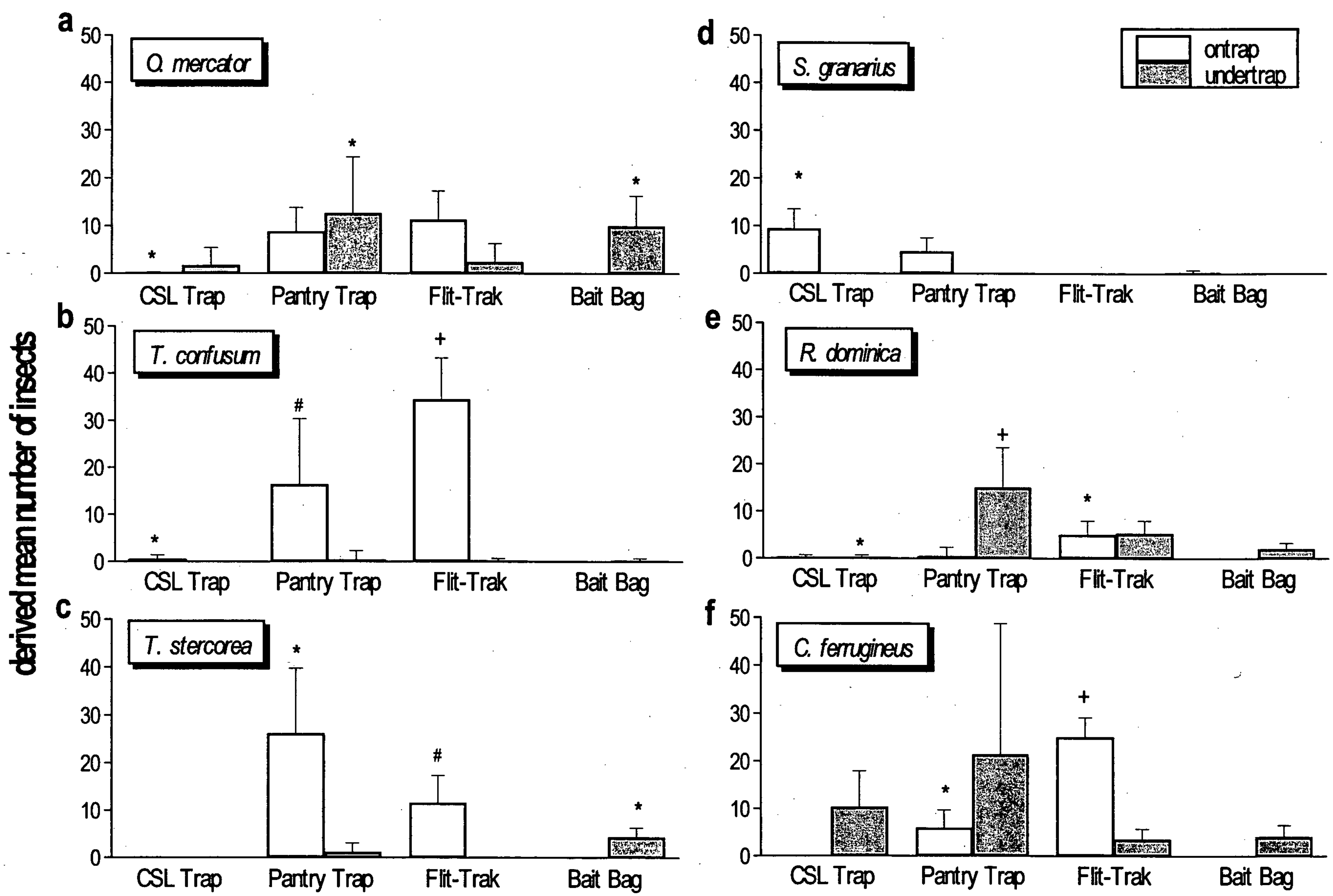


Figure 4: Lab test comparison of different trap types



error bars = 95% confidence limits, points with different symbols are significantly different from each other ($p < 0.05$)

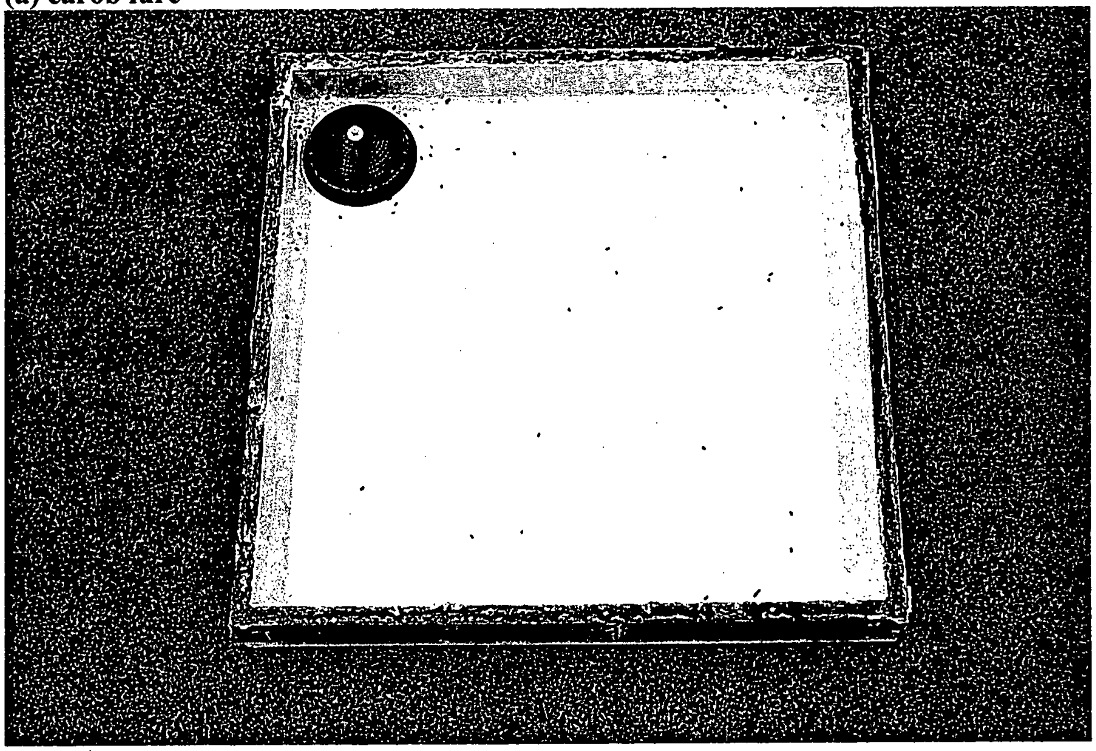
Figure 5: lab test comparison of trap types: insects on and under traps



error bars = 95% confidence limits, points with different symbols are significantly different from each other ($p < 0.05$)

Figure 6. ***S. granarius*** **with:**

(a) carob lure



(b) Flit-Trak oil lure