HGCA

PROJECT REPORT No. 113

THE EFFECTS OF CONVEYING ON INSECTS AND MITES INFESTING GRAIN INTENDED FOR EXPORT: SIGNIFICANCE WITH RESPECT TO CHEMICAL TREATMENTS

JULY 1995

PRICE £4.00

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THE EFFECTS OF CONVEYING ON INSECTS AND MITES INFESTING GRAIN INTENDED FOR EXPORT: SIGNIFICANCE WITH RESPECT TO CHEMICAL TREATMENTS

by

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This is the final report of a project which commenced in September 1992 and lasted for 21 months. The work was funded by a grant of £21,777 from the Home-Grown Cereals Authority (Project No. 0018/1/92).

Contents

ABSTRACT

Published information suggests that conveying results in substantial mortality of insects and the relevance of this is discussed in relation to journey times and the time required for populations to recover to their initial level. However, much previous information does not distinguish between different methods of conveying and many of the most dramatic reductions were observed when a pneumatic conveyer was used. A survey of the eastern region British ports suggested that belt conveyers, a much gentler form of conveyance were normally used and these were not expected to cause such useful reductions in insect numbers.

Six experiments have been carried out to determine the effect of conveying on insects. In 2 of these, an elevator was used to pass the contents of an infested 1 t bin into an empty bin; in the other 2, an auger was used and in the final 2 a pneumatic conveyer was the subject of investigations. There was a small reduction in live adult *O. surinamensis* using auger or elevator but *S. granarius* numbers apparently increased, probably because the disturbance knocked them out of the grain. In contrast, the pneumatic conveyer caused unequivocal reductions in insect number.

Exposing the *S. granarius* from these experiments to pirimiphos-methyl on treated filter papers did not show a difference between susceptibility of the insects before and after conveying.

A series of experiments to devise a standard process to damage insects was carried out. Shaking insects in jars containing grain had a greater effect than tumbling, with *T. castaneum* being unaffected and *S. granarius* being less affected than *O. surinamensis*. A device, comprising a plastic cylinder, suspended at its centre so it could be rotated through 360°, was used in an attempt to damage insects in a standard fashion. This did not apparently damage them sufficiently to increase their susceptibility to insecticides. A final test showed that repeated impacts caused by shaking insects in jars had no effect on the susceptibility of the 3 species of insects to 3 pesticides.

Overall, it seems that only pneumatic conveying is likely to inflict sufficient insect damage to cause heavy mortality. The relatively gentle forces experienced during conveying prior to export, mainly using belt conveyers, do not appear to cause sub-lethal effects that enhace insecticide treatments sufficiently to allow lower doses to be effective.

INTRODUCTION

The United Kingdom produced an annual exportable grain surplus of about 7.5 million tonnes since 1993 and the CAP reforms. The grain is usually outloaded from lorries or occasionally from silos at the ports. Because freedom from infestation is a quality requirement, pesticides are commonly applied as an insurance against the low probability of detecting existing infestations with current sampling methods. It is important to prevent infestation during export because the only on-board treatment available is fumigation which is very difficult and costly. With increasing grain surpluses in the U.K., the export trade must become increasingly important if cereal growing is to continue at the present level. In this very competitive area, the quality of British grain will be critical in determining export success.

Expense caused by the presence of live insects and to some extent also, live mites, include delays at the ports of departure and destination and the cost of treatment either by admixture or by on-board fumigation. Where there is a requirement for a phytosanitary certificate the cost of claused/refused certificates must also be considerable. On top of these quantifiable expenses, there is also the loss of good-will toward British exporters and suspicion about the quality of the product of future harvests.

It is therefore essential that measures are taken to ensure that grain for export will be predictably pest-free when unloaded and that there is full knowledge of all the processes, including conveying, involved with loading and treating the grain. However, there is a danger that Maximum Residue Limits could be exceeded, were the grain to be treated at all the various storage stages; on farm, in commercial stores and before export. The storage strategy developed by CSL for HGCA (Wilkin et al., 1990, Armitage et al., 1992) should minimise the necessity for chemical treatment. However, as it is based on cooling by low volume aeration, the grain for export will initially be at a low temperature. The efficiency of the chemical treatment depends on the chemical used, the application rate and the temperature of the grain. Grain from commercial British stores is likely to be at about 10°C, inhibiting the effectiveness of many pesticides. [(The low temperature efficacy of admixture chemicals was the subject of a parallel study by Kelly and Amos, (1993)].

The necessity or otherwise of treating export grain which is apparently uninfested, depends on the temperature at loading and the voyage time. If the voyage time is of shorter duration than that required for insects to complete their development or the grain temperature is too low to permit this, then there can be little infestation risk.

A further factor affecting export grain is the effect of mechanical handling. It is conveyed before transport to the port, during unloading into silos at the port, during loading onto the boat and during unloading at the end of the voyage. A fairly thorough review by Banks (1987) of the disparate information on impact and physical removal suggested that up to 99% mortality could be achieved during conveying. Better understanding of the effects of conveying and how these may be maximised should ensure that export grain is only treated when necessary at a saving of 20 p/t for admixture. This will also enhance the prospects of selling grain for export where there is a requirement for residue-free grain.

Wilkin and Rowlands (1988) claimed that the proportion of insects killed by conveying would compensate for the high control mortalities observed in their experiments on efficacy of chemicals at low temperature. They assumed these control mortalities were due to not acclimatising their test insects to low temperatures. Wilkin (1991) recommended that a limited investigation was required on the effect of conveying on insects in grain, particularly in relation to any enhancement of chemical treatments.

However, the proportion of the population destroyed will depend on the type of conveyer and whether or not there is an enhancing effect by chemicals. For instance, insects that might survive a journey due to slow insecticide action at low temperatures, might not do so if they were also damaged due to conveying. On the other hand, the likely enhancement of conveyer-induced mortality by low chemical doses may balance the requirement for higher doses needed to treat cold grain to ensure that the insecticide works sufficiently rapidly to kill pests before the grain is unloaded at a destination port.

This study examined the damage to insects during conveying and the effects of this on the enhancement of chemical treatment.

PART 1

A REVIEW OF THE CURRENT INFORMATION ABOUT THE EFFECT OF GRAIN CONVEYING ON ARTHROPODS AND ITS RELEVANCE TO GRAIN EXPORT PROCEDURES

D.M. Armitage

Conveying principles studied in the laboratory

1. Bailey (1962) achieved 86-98% mortality of *S.granarius* at impact velocities of 21-26 m/s with grain breakage of 2% (at 14% m.c.) at the lowest and 9-12% (at 10-12% m.c.) at the highest velocity.

2. Bailey (1969) estimated that dropping the grain 0.3-3m would kill 20-99% of developing *S.granarius* in cultures, in experiments where grain was projected against a steel block, 2-4 times weekly.

3. Loschavio (1978) achieved 50-97% mortality of *S.granarius* but only 20-50% mortality of *C.ferrugineus* with 1-7 drops from 14m of 400 g wheat-filled sacks.

4. Bailey (1969) found that pupae and pre-pupae of *Sitophilus* were most susceptible to disturbance.

5. Loschavio (1978) found that more adult insects died when impacted against a metal surface than when cushioned by several cm of wheat. *C.ferrugineus* mortalities of 2-95% were produced with 1-7 drops of 14 m.

6. Impact causes mortality but rotation or mild centrifugal forces do not (Bailey, 1962).

7. Velocities of about 64 m/s are required to disinfest grain (Stratil et al., 1987) but at these speeds, the grains are unacceptably damaged.

Practical and farm-scale experiments

8. Turning grain was used to reduce infestation, moisture and temperature (Gay, 1941) but the effect was usually attributed to mixing in of the out of high values of these qualities in the bulk.

9. Joffe (1963) discharged grain a distance of 9 feet, then through a series of belts every 2 weeks, approximately 13 times and noted infestation reductions in comparison with unmoved grain, that could not be accounted for by physical conditions alone.

10. The entoleter, a spinning disc with pegs, intended for flour products, used at half speed killed 99% of free-living insects without serious grain breakage (Cotton, 1958) but there was substantial survival of immatures.

11. Cogburn et al. (1972) killed 94-100% of immatures and over 99% of adult *Cryptolestes*, *R.dominica* and *S.oryzae* in a conveying chain including a screw auger, bucket elevator and pneumatic conveyer.

12. Kirkpatrick and Cagle (1978) killed 94-100% of adults and 63-77% of immatures in a similar test.

13. Green and Tyler (1966) achieved 95% mortality of *O.surinamenis* in a chain of mechanical handling including a pneumatic conveyer, elevator and other conveyers.

14. Muir et al (1977) noted 80-100% mortality of adults and larvae of *C.ferrugineus* during transfer by an unspecified means of conveying.

15. Fleurat-Lessard (1980) noted 80% mortality of immature *S.oryzae* by pneumatic conveying.

16. Rodionov (1938) noted that mortality of *S.granarius* of 33% one day after turning, rose to 92% after 12 days.

17. Bahr (1973) reduced an infestation of 132 *O.surinamensis*/kg to zero after pneumatic conveying at 25 t/h.

18. Bahr (1973) produced 96.4% and 99.8% mortality of *C.ferrugineus* and *O.surinamensis* after pneumatic conveying at 37.5 t/h.

19. In wheat conveyed pneumatically at 19 t/h, 48-99% mortality was observed for 5 species of insects, the greatest survival being for *S.oryzae* (Bahr, 1973).

20. During pneumatic conveying at 15 t/h, *R.dominica* and *C.ferrugineus* were reduced by 92.2% and 85.7%, despite the majority of the infestation being inside the grain (Bahr,1975).

21. Bahr (1991), summarising an extensive series of experiments using pneumatic conveyers, recorded that the minimum mortality for adult *O.surinamensis* was 95% with 81% for the stages within the grain and recommended that dangerous infestations should always be discharged using pneumatic conveyers.

22. Rees et al (1994) showed that about 77% of psocids and 80% of *Cryptolestes* were killed during transfer between bins using a conveyer and bucket elevator.

The effect of conveying on mites

23. Wilkin (1975) obtained 81% kill of *Tyrophagus* and *Glycyphagus* during conveying using chain and flight fed by auger and 90% control of *Acarus* in a series of chain and flight, bucket, elevator and chutes.

24. Wilkin and Hope (1973) achieved a 75% reduction in mite numbers in a similar conveying chain.

25. Megalov (1934) killed 69% of mites in rye falling onto plates inclined at 45° and 84% when the process was twice repeated.

26. Burrell (pers. comm.) achieved 98% reduction of *Cheyletus* and *Glycyphagus* by pneumatic conveying for 2 h.

27. Armitage (1994) reduced populations of *A.siro* and *G.destructor* by 70-98% during pneumatic and auger conveying.

Recovery in pest populations after conveying

28. Banks (1987) estimated that it would take 2-3.5 generations for insects to regain their former numbers after conveying achieved 95-99.9% mortality, assuming only

one stage (pupae) survived, or 1.5-2.5 generations, assuming a proportion of all stages survived.

29. Wilkin (1975) noted that 10 weeks after conveying, mite populations had recovered to exceed pre-conveying numbers.

30. Wilkin (1975) also recorded that 7 days after turning, mites had recovered to one-third of their pre-conveying numbers.

Relevance of these observations to conveying prior to export

From the above, it is clear that mortalities of over 90% are commonly achieved by conveying, within the range 80-100% for insects and 69-98% for mites. Many of the tests involved chains of conveyers, so it is difficult to determine the effect of each although the results using a pneumatic conveyer were particularly promising. The main survival was likely to be by pests hidden in the grains. The recovery of these infestations to detectable levels would therefore depend on the generation times of the individual common species, which are set out below.

Table 1
Generation times (egg to adult in days) for the 3 commonest British species of stored product grain beetle at 70 % r.h.

°C	15	20	25	30	35	Author
O.surinamenis	-	60	33	22	20	Howe 1956
C.ferrugineus	-	105	42	28	21	Smith 1965
S.granarius	144	57	37	26	-	Eastham and Segrove 1947

Table 2
Generation times (days) for the commonest British species of stored product mites.

r.h.	°C	10	15	20	25	30	Author
70	*G.destructor*	99 **	56	21	24	-	Cunnington, pers.comm.
75	*G.destructor*	146	50	30	22	21	Stratil et al. 1980
75	*G.destructor*		26	14	10		Barker, 1983
70	*C.eruditus*	82	50*	24	19*	15	Boczk,1959
70	*T.putrescentiae*	-	58	29	18	20	Cunnington, pers.comm.
70	*A.siro*	63	22	14	10	11	Cunnington, pers.comm.

* extrapolated
** v.high mortality

The time available for the pests to recover their populations after conveying depends on the journey length and the temperature of the grain at loading. Wilkin and Rowlands (1988) estimated that journeys ranged from about a week or less to the Baltic, Spain or Poland, through 1-2 weeks for Italy, Algeria, Libya, Saudi Arabia or the Black Sea, to as much as 40 days to Korea or China. They also recorded grain temperatures of 21°C, falling to 17 °C between August and December at Ipswich and 8°C to 14°C between April and June at Hull.

If the estimates of mortality caused by conveying and the recovery times are accurate, it seems unlikely that insect pests that were reduced to below detectable levels by conveying, could recover their numbers before the end of even the longest journeys unless significant warming of the grain occurred. However, there would be some danger of mites doing so, in view of their shorter generation times. These small risks could be further lessened by ensuring grain was never more than 15°C or 65% r.h. Finally, it should not be forgotten that unloading the grain might inflict further heavy mortality on any infestations, detected or undetected.

Collection of information on conveying machinery used at major, grain-export ports.

Kelly (1990) produced a most useful review of the grain exporting and certification facilities in the ADAS Eastern region. This included details of how ships were loaded and illustrates the equipment used. His data are summarised below.

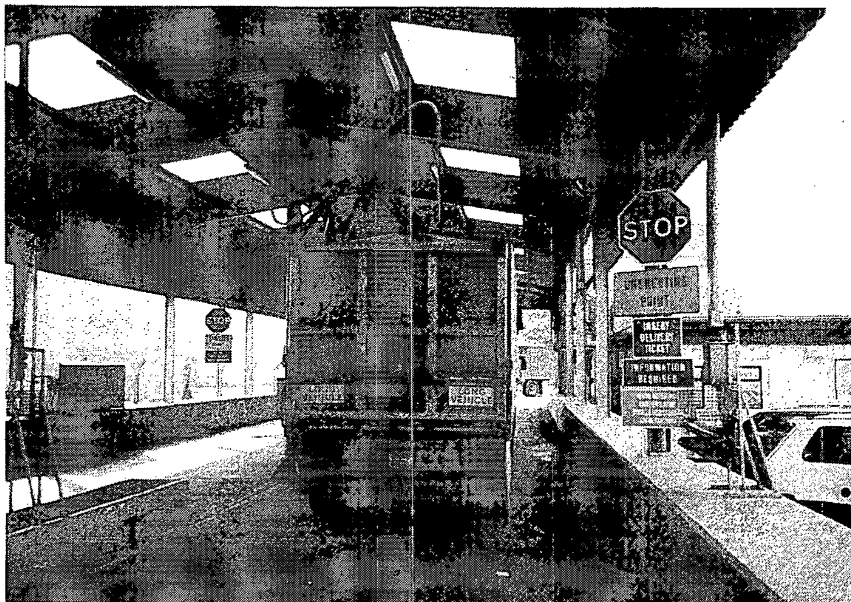
Table 3
The incidence and percent of different modes of loading ships at 21 sites and 11 ports in the Eastern region (Some sites use more than one method).

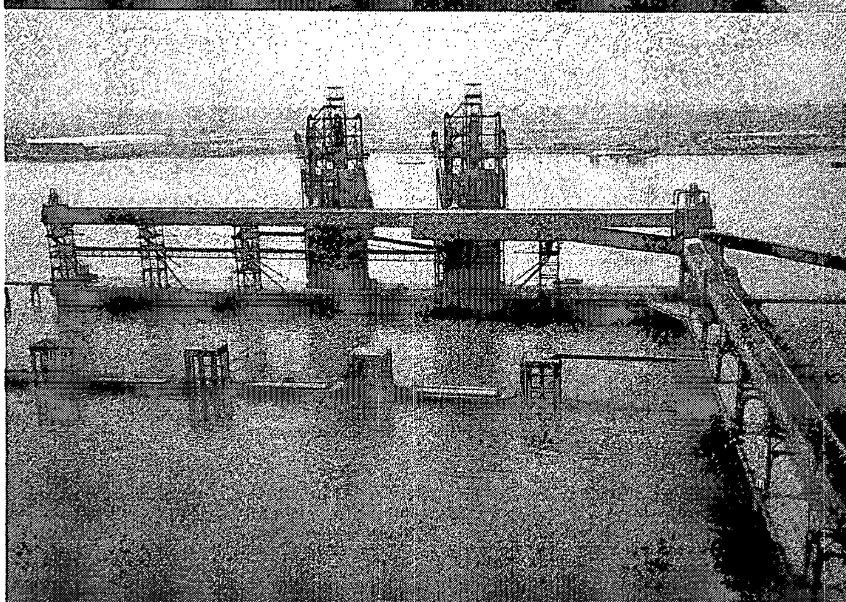
Fixed overhead conveyer	Direct from Pit	Lorries/mobile elevators	Silo to ship	Lorries-pit-silo outloading
2.5	0.5	13.3	4.5	1.5
11.2%	2.2%	59.7%	20.2%	6.7%

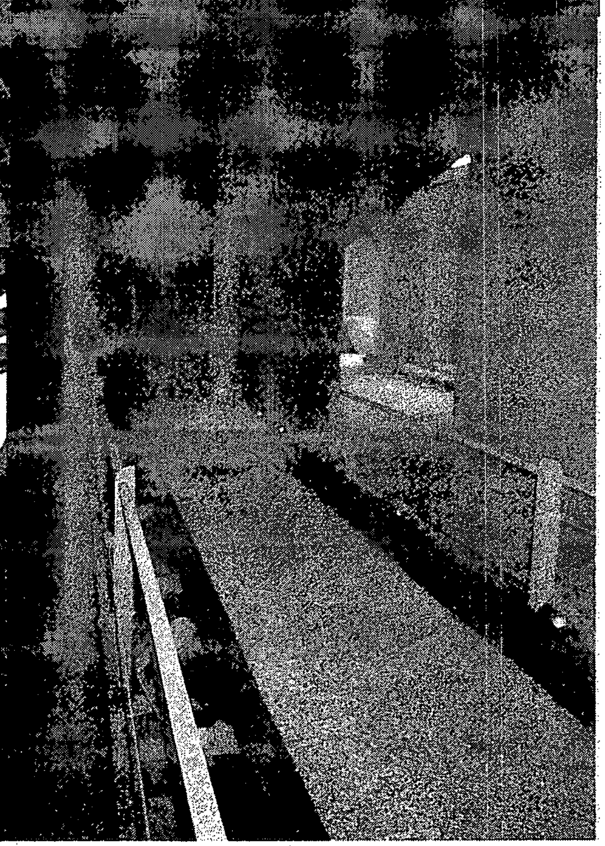
Although the entries under 'Grain loading system' in the report are not specific, it is evident from the detailed illustration that the mobile elevators are conveyers in which the grain is carried on a moving rubber belt, with little damage possible to the insects, until the grain falls into the hold. Discharges from fixed overhead conveyer, direct from the pit, from silo to pit and from lorries via silos generally involve screw-type augers.

Fig. 1

Grain handling sequence at an export terminal. Top left; automatic sampling as lorry arrives, top right; lorries queueing for weighing, middle left; conveyer run to the dock, bottom left and bottom right; belt conveyers at the terminal.


STOP





PART 2.

THE EFFECT OF CONVEYING ON INSECTS

D.M. Armitage, C. Duckett and D. Cook

METHOD

Two 1 t conical bins were filled with wheat at 15 % m.c. and placed in a barn maintained at 25°C (+/- 1°C). About 8,250 *S.granarius* and 6,550 *O.surinamensis* from cultures maintained at 25°C and 70% r.h., were then added to the grain. This was done by emptying grain from a hollow tube by vacuum and tipping in the contents of jars containing known numbers of insects. This was carried out in 3 rows and 5 columns (n=15). The insects were put in place on 4 July 1993 and left to breed up to numbers detectable by conventional sampling. This is at least 5/kg (Wilkin and Fleurat-Lessard, 1992). On 19 September '93 the effect of conveying using an auger was assessed by passing the contents of one bin into an empty bin of the same size (Fig 1). The same process was then repeated by discharging the contents of the bins into a pit attached to a barn, from whence it was conveyed back into an empty 1 t bin using an elevator and overhead discharge (Fig 2).

The infestation before and after conveying was assessed by taking 20 samples of 200g by gravity spear from 5 columns and 4 rows in the infested bin before conveying and also from the bin into which it was conveyed. Conveying the 1 t took about 15-20 minutes. In addition, 10 samples of 1 kg were also taken during conveying from discharges of the infested bin and the conveyer. The numbers of live and dead insects were determined by sieving through a 2 mm mesh

After conveying, the samples were stored at 10°C, to minimise mortality and to slow the emergence of developing insects. Processing of samples took 1-2 weeks.

After a further 11 weeks, on 4 November '93, the procedure was repeated, passing one infested bin through the auger and the other through the elevator.

The final experiment was delayed until April 1995, due to breakdown of the pneumatic conveyer and the necessity of setting up fresh batches of infested grain. The sampling process was carried out as previously but as earlier results of assessing the numbers of dead insects had not proved instructive, only live insects were counted.

For the first test, only one bend was inserted into the pipe run and in the second, 2 bends were used (Fig. 4).

RESULTS

O.surinamensis

Effect of auger- The 200 g samples suggested a decrease in numbers of live insects by 32% and 62% (Table 1) in 2 experiments while the 1 kg samples suggested decreases of 40% and 61%. Equivalent increases in the nos. dead were not noted however and decreases occurred in 3/4 of the experiments.

Effect of elevator- Decreases of 9% and 35% were noted, based on the 200 g samples and a decrease of 44% in the first experiment, based on 1 kg samples. However in the second experiment, the 1 kg samples suggested an increase in the infestation after conveying. Increases in the proportion of insects dead were noted based on the 200g but not the 1 kg samples.

Effect of pneumatic conveyer- In the first experiment, decreases of 99%, based on 200g samples or 88%, based on the 1 kg samples were noted. In the second experiment, numbers of this species were too few for comment, however some survivors were noted.

S.granarius

Effect of auger- Based on the 200 g samples, the auger appeared to increase the live infestation but based on the 1 kg samples, it was decreased by 16 and 21%. The proportion of dead decreased except based on the 1 kg samples, in the first experiment.

Effect of elevator- Based on the 200 g samples, the elevator increased the number of live insects while in the first experiment, the 1 kg samples suggested a 7% decrease while the second suggested a 45% increase. Based on 200 g samples, the proportion dead appeared to increase, while based on 1 kg samples, it apparently decreased.

Effect of pneumatic conveyer- Reductions of 78% and 30% were noted in the first experiment, based on the 200 g and 1 kg samples respectively. In the second experiment, the comparable reductions were 95% and 47%.

DISCUSSION

Effects of auger and elevator

Three out of 4 experiments showed decreases of both *O.surinamensis* and *S.granarius* during conveying, based on 1 kg samples and all 4 experiments produced reductions in *O.surinamensis*, based on the 200 g samples. Nevertheless, most of the insects survived conveying by elevator or auger and the grain still had sizeable infestations after handling.

The results show many discrepancies. For instance, the number of live insects did not always rise to account for the numbers killed by conveying. This is not unexpected and is probably accounted for by the fragmentation during grain handling and the increased difficulty in finding the insect pieces.

Another major discrepancy is that the numbers of live insects actually appeared to increase after handling. This may be a real observation, caused by the disturbance causing insects to fall out of the holes in the grain. This is in part borne out by the fact that this effect was most noticeable with *S.granarius* which spends a good proportion of its time within the grain. Another explanation is sampling error. Insects are not randomly distributed and the 200 g sampling of the static bulks would therefore be less accurate than the 1 kg sampling from the moving grain discharge. Again, this effect is most noticeable with *S.granarius* where in 3/4 experiments, the 1 kg samples showed a decrease in live insects after conveying but in no experiments did the 200 g samples show a decrease.

Despite these discrepancies it is unequivocal that a high proportion of insects survive conveying by auger or by elevator and therefore that they do not have a useful effect of reducing infestations, contrary to much of the published information .

Effect of pneumatic conveying

The results of experiments using the 'sucker-blower' were much less equivocal than those using alternative conveying methods. The one experiment in which large numbers of *O.surinamensis* were available showed a decrease by both methods of assessment that was close to previously published figures (see Part 1). Decreases in *S.granarius* were also shown in both experiments and for both sampling methods although the decreases estimated using the 1 kg samples were less than half those estimated using the gravity spear samples.

Fig. 2

Effect of conveying using an elevator upon insects. Above left:- sampling before conveying. Above right:- Sampling after conveying Lower left- Infested grain in 1 t bin passes into pit by slide , up elevator and is discharged into second 1t bin .

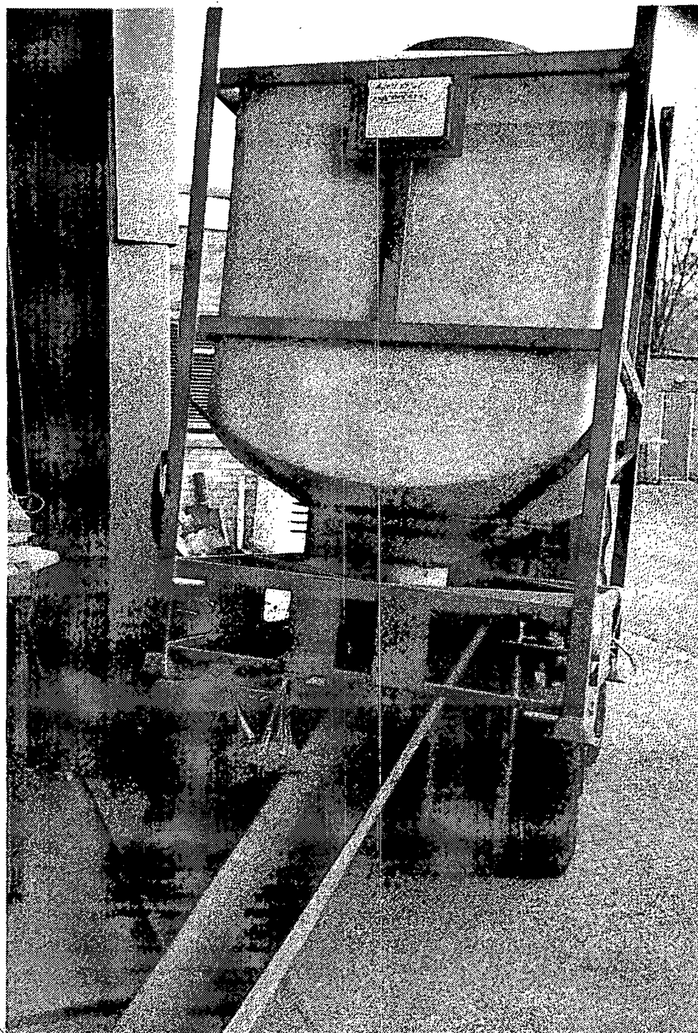


Fig. 3

Effect of conveying by auger on insects. Above left- sampling before conveying. Above right- sampling after conveying. Below- Infested grain in bin passes through conveyer into a second 1 t bin .

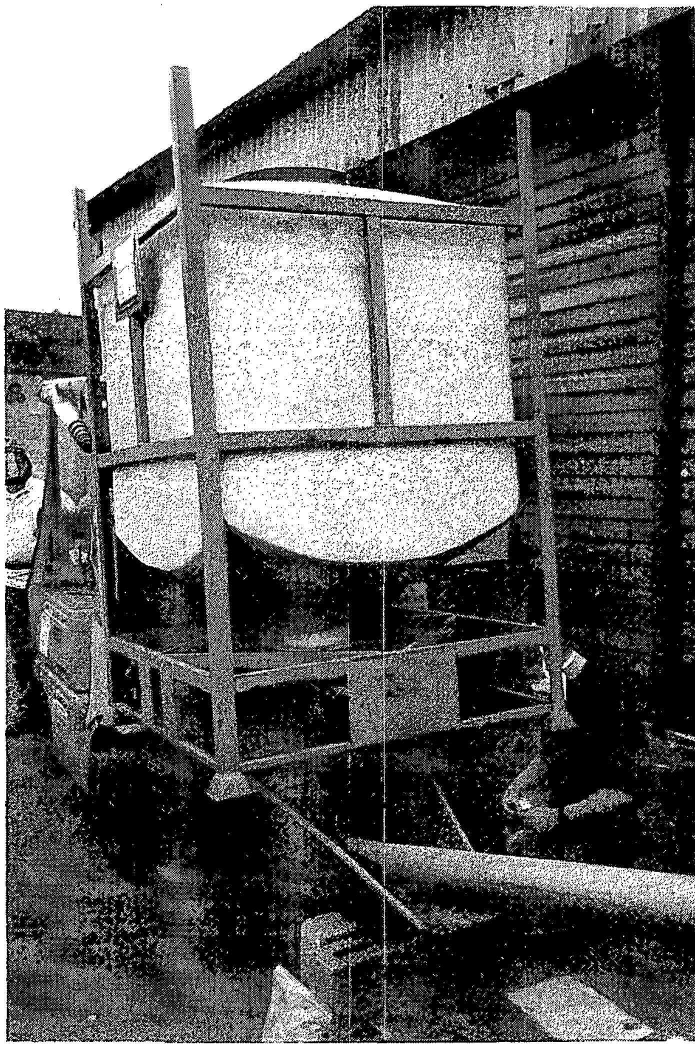
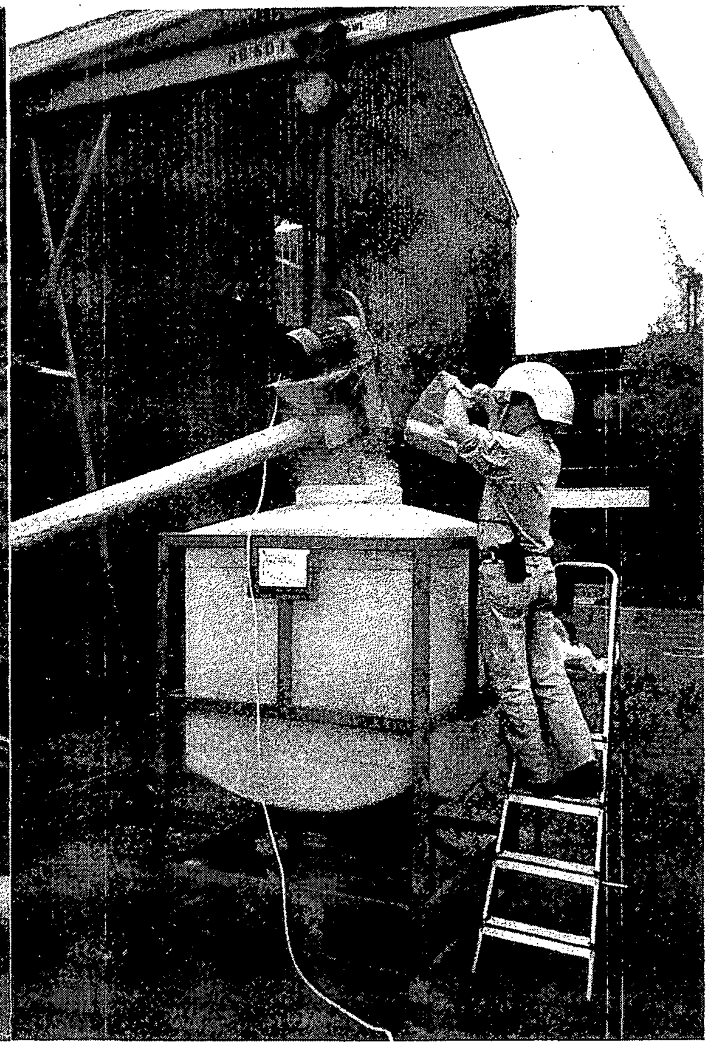
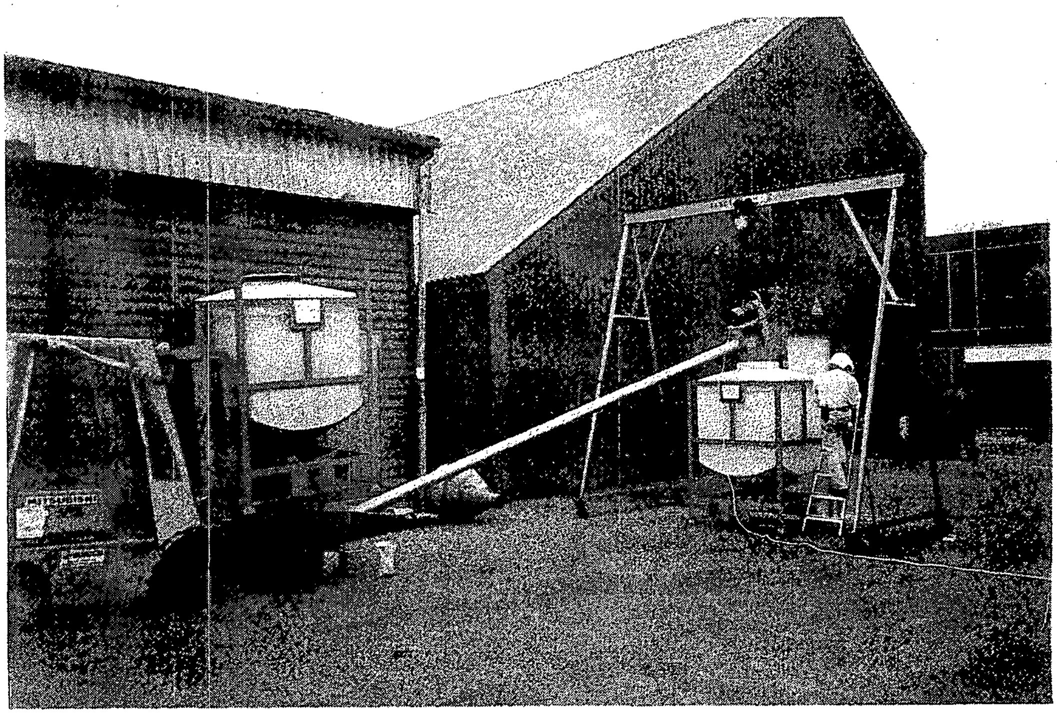




Fig 4

Top and middle: Conveying between bins using pneumatic conveyer. Bottom: second experiment using double bend on discharge side.

Table 4
Numbers/kg *O.surinamensis* before and after conveying (S.E. in parentheses)

a) Auger	n		Exp. 1 Before	After	% Change	Exp. 2 Before	After	% Change
200g	20	alive	9.6 (1.73)	6.4 (1.60)	**-33**	12.2 (1.90)	4.6 (1.34)	**-62**
		dead	7.7 (1.86)	14.0 (2.61)	**+82**	11.2 (1.23)	8.7 (1.63)	-23
1000g	10	alive	26.7 (3.67)	16.1 (2.57)	**-40**	21.2 (8.22)	8.2 (3.15)	**-62**
		dead	2.4 (0.41)	1.5 (0.41)	-36	23.3 (4.00)	15.5 (2.73)	-33
b) Elevator								
200g	20	alive	9.5 (1.86)	8.6 (2.03)	**-9**	100.1 (31.55)	64.9 (13.86)	**-35**
		dead	1.4 (0.57)	4.0 (0.81)	**+186**	40.0 (4.52)	45.9 (8.62)	**+15**
1000g	10	alive	22.3 (4.53)	12.4 (1.59)	**-44**	63.9 (15.75)	106.8 (19.92)	+67
		dead	6.0 (2.05)	0.4 (0.20)	-94	61.1 (9.51)	45.6 (14.71)	-25
c) Pneu-matic								
200g	20	alive	333.6 (23.7)	4.0 (2.00)	**-99**	2.0 (0.40)	2.0 (0.40)	-
1000g	10	alive	234 (151)	29.7 (16.3)	**-88**	0.1 (0.1)	0 (0)	-

Table 5
Numbers/kg of *S.granarius* before and after conveying (S.E. in parentheses).

a) Auger	n		Exp.1 Before	After	% Change	Exp. 2 Before	After	% Change
200g	20	alive	3.3 (1.51)	26.4 (3.24)	+707	155.6 *(24.81)*	632.1 (88.35)	+306
		dead	2.3 (0.99)	5.7 (1.33)	+146	33.7 (4.01)	164.2 (11.69)	+387
1000g	10	alive	16.1 (3.38)	13.5 (3.54)	**-16**	370.1 (95.56)	292.3 (192.5)	**-21**
		dead	8.5 (4.58)	2.1 (1.17)	-75	90.9 (17.27)	141.5 (34.14)	+55
b) Elevator								
200g	20	alive	1.8 (0.68)	18.6 (2.16)	+910	207.2 (70.08)	533.7 (93.69)	+158
		dead	1.2 (0.45)	3.0 (0.89)	+ 163	63.5 (9.04)	139.9 (1.69)	+120
1000g	10	alive	15.0 (2.67)	13.9 (1.69)	**-7**	269.2 (108.48)	390.3 (151.14)	+45
		dead	4.5 (1.87)	3.2 (1.69)	-30	125.3 (52.74)	120.9 (17.08)	-4
c) Pneu-matic								
200g	20	alive	904.4 (270.40)	202.4 (86.80)	**-78**	804.8 (186.00)	41.6 (10.00)	**-95**
1000g	10	alive	549 (333)	387 (209)	**-30**	404 (103)	213.1 (56.9)	**-47**

PART 3.

EXPERIMENTS TO DETERMINE THE ENHANCEMENT OF INSECTICIDE TREATMENT BY 'DAMAGE' TO INSECTS.

D.A. Collins, T. Binns and S. Holloman

MATERIALS

Insects : The insects used in this study were laboratory susceptible strains of *T. castaneum*, *S. granarius* and *O. surinamensis*. The insects had been reared in constant conditions of 25^{o}C and 70% rh. Known age adults were used; *T. castaneum* when 3-5 weeks old, *S. granarius* when 2-4 weeks old and *O. surinamensis* when 0-2 weeks old.

Wheat : English milling wheat of the 'Mercia' variety was used in this study. The wheat was pesticide free and possessed a moisture content of about 15%, as determined by BS. 4317.

Pesticides : Commercial emulsifiable concentrate formulations of pirimiphos-methyl (Actellic), etrimfos (Satisfar) and chlorpyrifos-methyl (Reldan) were used in the investigation. These contained 250, 525 and 500 g/l active ingredient respectively.

A. EXPERIMENTS TO DETERMINE THE EFFECT OF PHYSICAL IMPACT.

Introduction

Impact has been found to produce substantial mortality whereas mild centrifugal forces and rotation, often associated with impact, in practice do not (Banks, 1987). The effect of conveying grain, where forces of impact are likely to occur, may therefore increase insect mortality and reduce the need for extensive pesticide treatments. In this preliminary experiment, we investigated the effects of disturbance on insect mortality.

Aim

The aim of this preliminary experiment was to determine the effect of the forces of impact induced by tumbling grain mechanically and turning by hand, on susceptible strains of insects.

Method

200 g of grain were weighed and put into 2 lb 'Kilner' jars. Four replicate jars were prepared for each test. The jars were closed with a filter paper lid and left to condition overnight in constant conditions of 25°C and 70% rh. Batches of 25 insects were removed from culture and placed onto the grain. The jars were closed with screw-caps and four replicates were then subjected to one of the following:

i) Held at an angle of 45° on a mechanical tumbler and turned, end over end for 15 minutes at a rate of 31 rotations per minute.
ii) Turned forcibly by hand, end over end, through 180° for 50 turns.
iii) Control - left undisturbed.

The jars were re-closed with a filter paper lid and left under constant conditions of 25°C and 70% rh for 7 days. After this period the contents were emptied onto an enamelled tray and the numbers of live, knocked-down and dead insects were recorded.

Results and discussion

Tumbling and turning the grain by hand had no effect on *T. castaneum*, as there was 0% mortality in each case (Table 6). There was an increased mortality observed with *S. granarius*, although there was no significant difference between the mortalities of insects in grain that was tumbled, turned or undisturbed. With *O. surinamensis* a significantly higher ($p < 0.05$) mortality was observed with insects subjected to hand turning of grain compared to controls. Also a significant difference ($p < 0.05$) was also observed between the mortalities in turned and tumbled grain. The difference in the mortalities of insects subjected to the two forms of disturbance may be explained by the fact that turning the grain had a greater force of impact, whereas the tumbling was a more prolonged yet gentler movement.

Dead insects that had been subjected to the physical disturbance were found to be missing antennae, legs and have distorted heads and abdomens. The lower mortalities observed in *S. granarius* and *T. castaneum* may be explained by their compact shape, relative hardness and habit of pulling in their legs and antennae.

Conclusions

The physical disturbances had no effect on *T. castaneum*, a slightly greater effect on *S. granarius*, and the greatest effect of *O. surinamensis*. The experiment demonstrates that different species are more or less susceptible to physical disturbance than others. This has also been documented by Bryan and Elvidge (1977). If conveying is to be used as part of an integrated approach to controlling grain pests the effect on different species must be considered.

B. EXPERIMENTS TO PRODUCE A STANDARD METHOD OF 'DAMAGING' INSECTS

Introduction

A previous experiment (section A) found that forcibly hand turning jars containing grain and insects, produced significantly higher mortalities of *O.surinamensis* compared to undisturbed insects. However, we wanted to simulate more closely the disturbance that may be encountered during the conveying of grain. We therefore designed a piece of apparatus to produce similar forces of impact.

Aim

The aim of this preliminary experiment was to investigate a standard method of damaging insects, using a specially constructed apparatus designed to provide forces of impact.

Apparatus: The apparatus devised to damage insects in these experiments consisted of a rigid PVC tube measuring 180 cm in length, with an internal diameter of 8 cm. Both ends of the tube were closed with screw-on lids. The tube was attached at the centre of its length to a metal stand approximately 90 cm high, in such a way that it could be rotated around 360° or secured at any desired angle.

Method

Batches of approximately 50g of grain were put into 120 ml wide-necked bioassay jars. The jars were closed with a filter paper lid and left overnight at 25°C and 70% rh. Eight replicate jars were set up for each insect species. Four of these were used for undamaged insects, to act as controls, while the remainder were used for insects that were damaged in the following way:

A plastic, cylindrical container measuring 6.5 cm in diameter x 14.5 cm high was half-filled with grain. One hundred adult insects of each species were counted out from the laboratory culture and put onto the grain. The container was then closed with a lid. The PVC tube was secured in a vertical position and opened at the top end. The container was then put down the tube and the end was closed. The tube was then turned through 180° 10 times. The tube was opened and the container removed.

The contents of the container were emptied onto an enamelled tray and the insects separated, using a pooter, into 4 batches of 25 insects per species. Each batch was added to the grain in the 4 previously prepared replicate bioassay jars. A further 4 batches of 25 insects were removed from the laboratory culture and added undamaged to the remaining 4 replicate jars. The jars were closed and left in the constant conditions of 25° C and 70% rh for 7 days.

After this period the jars were opened and the contents emptied onto an enamelled tray. The numbers of live, injured and dead insects were recorded, together with details of the damage caused.

The whole experiment was then repeated on 4 occasions with the tube turned 20, 30, 40 and 50 times.

Results and discussion

Analysis of variance, showed there to be no significant difference between the control and damaged mortalities for each insect species for the different number of turns (Table 7).

The apparatus used did not significantly increase insect mortality compared to the undamaged controls. Increasing the number of turns from 10 to 50 also had no effect on insect mortality. *O. surinamensis* appeared to be the most susceptible insect, however the high control mortalities observed did not make this significant. The reason for the high control mortalities is not known but has been observed in other work and have been due to the long exposure period (7 days) on whole grains. A sample of the grain was sent for pesticide residue analysis to confirm that it was pesticide-free.

C. EXPERIMENTS TO DETERMINE THE EFFECT OF INSECTICIDE ON DAMAGED INSECTS.

Introduction

This experiment was a continuation of preliminary studies investigating the effects of physical damage, induced during the conveyance of grain, on insect mortality. A previous experiment (section B) showed no significant difference in insect mortality between those put through the apparatus and the undamaged controls. Although low mortalities were recorded for the 'damaged' insects, they may have suffered minor cuticular damage that did not result in death. However a combination of physical disturbance and low pesticide dose may lead to increased mortality.

Aim

The aim of this experiment was to investigate whether the combined effects of damage induced by physical disturbance and a low pesticide dose, may lead to increased mortality compared to when either of the effects were used alone.

Method

Batches of 500 g of grain were spread evenly onto an enamelled tray. A pesticide dose of 0.14 mg/kg was prepared using distilled water as a diluent. This dose was calculated from previous work in order to produce approximately 50% mortality of susceptible insects. The grain was sprayed with 5 ml of the pesticide solution using a hand held 'De Vilbis' paint sprayer. After treatment the grain was transferred into 'Kilner' jars and tumbled for 15 minutes to ensure that the pesticide was evenly distributed. A batch of grain was similarly treated with 5 ml of distilled water to act as a control.

Each batch of treated and control grain was divided into approximately 50 g aliquots and put into separate 120 ml wide necked jars. Eight replicate jars were set up each for the treated and control grain for each insect species. The jars were closed with filter paper lids and left for 24 hours at 25°C and 70% rh.

The insects were damaged, as previously described in Part 3B but 200 insects were placed in the grain.

Afterwards, the contents of the container were emptied onto an enamelled tray and the insects separated, using a pooter, into 8 batches of 25 insects per species. Four of the batches of each species were put separately into 4 replicate jars containing the treated grain and 4 were put into jars containing untreated control grain.

A further 8 batches of 25 insects per species were removed from the laboratory culture. Four of the batches were added undamaged to the 4 jars containing the treated grain and the remaining 4 batches to the jars with the control grain.

The jars were closed and left in the constant conditions of 25°C and 70% rh for 7 days. After this period the jars were opened and the contents emptied onto an enamelled tray. The numbers of live, knocked down and dead insects were recorded.

Results and discussion

Analysis of variance showed that, for each insect species, there was a significant difference ($p < 0.05$) between the insect mortalities on the treated and untreated grain, but not between the mortalities of insects that had been damaged and those that were undamaged (Table 8).

The physical disturbance induced by turning the insects in the apparatus did not significantly increase mortality compared to the undamaged controls. The combination of a low pesticide dose and physical disturbance also did not increase the mortality of the insects compared to the effect of the pesticide on its own. This suggests that the mortalities were due to the effect of the pesticide rather than to the physical disturbance. This indicates that the apparatus used in this experiment does not cause any significant damage to the insects which would make them more susceptible to pesticide treatment.

D. THE COMBINED EFFECTS OF PESTICIDE TREATMENT AND PHYSICAL DISTURBANCE OF GRAIN, ON INSECT MORTALITY

Introduction

Previous experiments (sections B and C) found that a piece of apparatus designed to produce forces of impact, did not cause significant damage to the insects which would make them more susceptible to the effects of pesticide treatment. A previous experiment (section A) found that significantly higher mortalities of *O.surinamensis* occured using 'hand turning' than when they were left undisturbed. We therefore decided to revert to this method of producing disturbance.

Aim

The aim of this experiment was to produce dose response data, using grain admixed with 5 doses of pesticide, for insects subjected to 50 hand turns and for insects left undisturbed; to determine if any damage induced by the physical disturbance would enhance the effect of the pesticide.

Method

A series of five pesticide doses were prepared for each test by serial dilution of the highest dose, using distilled water as a diluent. Separate batches of 500 g of wheat were then spread evenly as a single grain layer over the base of a 330 mm x 560 mm enamelled tray and sprayed with 5ml of the required dose, using a hand-held 'De Vilbis' paint sprayer. After treatment, each batch of wheat was transferred into a 1.5 litre 'Kilner' jar and mixed on a tumbler for 15 minutes to ensure the pesticide was evenly distributed. A batch of wheat was similarly treated with 5ml distilled water, to act as a control.

Samples of approximately 100 g of treated and control wheat were also sent to be analysed for pesticide residues by the Panel method (Anon, 1980).

The treated and control batches of wheat were left to equilibrate overnight at room temperature, after which time the jars were tumbled for a further 10 minutes. Each batch of treated and control wheat was then divided into 50 g samples and placed in a 120 ml wide necked bioassay jar. The inner rims of the jars to be used for tests with *S. granarius* and *O. surinamensis* were previously coated with fluon to prevent insects from escaping. Six replicate jars were prepared for each pesticide dose and control. The jars were then stored at 25^{o}C and 70% rh overnight to equilibrate.

Forty batches of 25 insects of each species were counted out from the laboratory cultures. For each test species, a single batch of insects was added to each of 3 replicate bioassay jars of treated and control wheat. The remaining insect batches were combined and put into a 2lb 'Kilner' jar containing approximately 200 g of untreated wheat. The jar was then turned forcibly by hand, end over end, for 50 turns. The contents of the jar were then emptied onto a tray and any dead insects were counted and removed. The remaining live insects were separated using a pooter, into batches of 25 insects per species. These were then added to the remaining 3 replicate bioassay jars of treated and control wheat.

The jars were closed with a filter paper lid and left in the constant conditions of 25^{o}C and 70% rh for 7 days. After this period the jars were opened, the contents emptied onto an enamelled tray and the numbers of live, knocked down and dead insects were recorded. An insect was considered knocked down if it was on its back and unable to right itself, even if aided with a small brush; it was considered dead if no visible movement was detected. The results were assessed using mortality after 7 days exposure to the treated wheat as a criteria of response. They were subjected to probit analysis and the numbers of dead insects in each individual dose were compared using analysis of variance.

Results

No mortality was observed with *S. granarius* and *T. castaneum* immediately after being subjected to the physical disturbance, with only 1.75% mortality of *O. surinamensis* recorded.

The results of the probit analysis for the disturbed and un-disturbed insects of each species are shown in tables 9-11. They show no significant difference in response between the disturbed and un-disturbed insects of any of the test species, exposed to any of the pesticides.

Comparisons of the numbers of dead insects in each individual dose, by analysis of variance, also showed no significant difference in the mortalities of disturbed and un-disturbed insects at the 95% confidence level.

Discussion

The low mortalities recorded directly after turning the jar suggest that the physical disturbance alone had little effect on the insects. Different species have been shown to have different levels of susceptibility to physical disturbance (Bahr, 1975). *S. granarius* is less susceptible than *O. surinamensis*, which is probably due to their relative hardness, compact shape and habit of pulling in their legs and antennae (Bryan and Elvidge, 1977).

The results of the probit analysis show little or no difference in the KD_{50} and $KD_{99.9}$ values for the insects subjected to the physical disturbance and those that were not. However in some cases, low probability values ($p < 0.05$) were recorded for insects that were subjected to the turning. This is partly due to the very narrow dose ranges it was necessary to use in order to produce dose-response data. However, the data also indicated a variation in the responses of the insects within replicate batches, which may suggest that physical disturbance did have some adverse effect on individual insects within different replicates, which made them more susceptible to the effect of the insecticide than others. However, this effect did not significantly increase mortality compared to the insects that remained undisturbed.

Although other workers including Joffe and Clarke (1963) and Loschiavo (1978) have found substantial mortalities resulting from physical disturbance, the methods of causing the disturbance are numerous. A preliminary experiment (section A) at this laboratory found significantly higher mortalities of *O. surinamensis* subjected to turning in jars containing grain, compared to those that had not. This effect, however, was not observed in this experiment indicating possible variations in sensitivity of the insects to disturbance.

Conclusions

The conclusions drawn from this experiment indicate that the effect of repeated impacts, induced by turning insects in jars containing grain, had no significant effect on mortality. The mortalities that were observed, were due to the effect of the pesticide treatment and not the effect of the physical disturbance. However, the effect of the physical disturbance may have increased the susceptibility of individual insects to the pesticide.

Table 6
Mortality produced (%) of susceptible strains of 3 species of stored-product grain beetle by mechanically tumbling and shaking grain

Type of disturbance	*T.castaneum*	*S.granarius*	*O.surinamensis*
Control	0	2 (0-4)	1 (0-4)
Hand shaken	0	8 (4-16)	26 (8-40)
Mechanically tumbled	0	6 (0-12)	4 (0-12)

Table 7
The effect of turning insects in a standard apparatus on their mortality (%).

No.	*T.castaneum*		*S.granarius*		*O.surinamensis*	
turns	control	damaged	control	damaged	control	damaged
10	0	3 (0-12)	4 (0-12)	10 (4-15)	19 (4-28)	33 (4-88)
20	0	0	2 (0-8)	3 (0-12)	15.9 (0-28)	12 (4-28)
30	0	0	4.9 (0-16)	2 (0-4.)	8 (0-20)	19 (4-28)
40	1 (0-4)	1 (0-4)	5 (0-8)	3 (0-8)	14 (8-20)	18 (0-57)
50	0	1 (0-4)	7 (4-12)	4 (0-8)	15 (0-28)	15 (8-58)

Table 8
Mean % mortalities of 3 insect species exposed to treated grain and physical disturbance

Treatment/Damage	*T.castaneum*	*S.granarius*	*O.surinamensis*
Untreated/Undamaged	0	2 (0-4)	5.9 (4-8)
Untreated/Damaged	1 (0-4)	3 (0-12)	2.9 (0-8)
Treated/Undamaged	27 (12-40)	19.7 (12-26.9)	100
Treated/Damaged	37 (8-52)	30.8 (11.1-48)	100

Table 9

Probit analysis comparing mortality after 7 days of undisturbed and tumbled *O.surinamensis* exposed to 3 insecticides.

Pesticide		KD 50 (mg/kg)	95 % limits	KD 99.9 (mg /kg)	95 % limits	Slope	S.E.	Chi-sq.	d.f.	P
Pirimiphos-methyl	Control	0.11	0.10 - 0.12	0.21	0.19 - 0.26	10.78	1.25	12.93	7	0.07
	Tumbled	0.1	0.06 - 0.17	0.23	0.15 - 13.24	6.39	2.44	198.24	13	< 0.001
Etrimfos	Control	0.07	0.06 - 0.07	0.1	0.09 - 0.14	16.28	2.87	21.84	7	0.0032
	Tumbled	0.06	0.05 - 0.06	0.11	0.09 - 0.17	12.37	2.51	33.59	9	< 0.001
Chlorpyrifos-methyl	Control	0.39	0.34 - 0.51	1.9	1.09 - 6.9	4.52	0.93	11.17	7	0.13
	Tumbled	0.32	0.28 - 0.39	1.8	1.07 - 5.28	4.13	0.74	16.35	10	0.09

Table 10

Probit analysis comparing mortality after 7 days of undisturbed and tumbled *S.granarius* exposed to 3 insecticides.

Pesticide		KD 50 (mg/kg)	95 % limits	KD 99.9 (mg/kg)	95 % limits	Slope	S.E.	Chi-sq.	d.f.	P
Pirimiphos-methyl	Control	0.21	0.20 - 0.22	0.35	0.32 - 0.41	13.74	1.62	11.89	7	0.1
	Tumbled	0.2	0.19 - 0.21	0.43	0.38 - 0.51	9.59	0.98	15.89	13	0.26
Etrimfos	Control	0.16	0.15 - 0.17	0.33	0.29 - 0.43	9.81	1.32	9.93	10	0.45
	Tumbled	0.15	0.13 - 0.16	0.43	0.35 - 0.60	6.59	0.79	16.78	10	0.08
Chlorpyrifos-methyl	Control	0.11	0.10 - 0.12	0.33	0.26 - 0.50	6.69	0.92	13.28	10	0.21
	Tumbled	0.11	0.09 - 0.13	0.22	0.17 - 0.52	10.09	2.44	42.49	10	<0.001

Table 11

Probit analysis comparing mortality after 7 days of undisturbed and tumbled *T.castaneum* exposed to 3 insecticides.

Pesticide		KD 50 (mg/kg)	95 % limits	KD 99.9 (mg/kg)	95 % limits	Slope	S.E.	Chi-sq.	d.f.	P
Pirimiphos-methyl	Control	0.14	0.13 - 0.15	0.57	0.46 - 0.78	5.11	0.49	14.93	10	0.14
	Tumbled	0.14	0.13 - 0.15	0.61	0.49 - 0.84	4.87	0.47	16.63	10	0.08
Etrimfos	Control	0.33	0.32 - 0.34	0.57	0.52 - 0.66	12.92	1.3	9.99	7	0.19
	Tumbled	0.31	0.29 - 0.34	0.6	0.50 - 0.91	10.89	1.74	19.02	7	0.009
Chlorpyrifos-methyl	Control	0.32	0.31 - 0.32	0.42	0.4 - 0.45	24.02	2.09	12.24	7	0.09
	Tumbled	0.31	0.31 - 0.32	0.4	0.39 - 0.42	28.42	2.4	5.65	4	0.23

PART 4.

EFFECT OF INSECTICIDE TREATMENT ON *SITOPHILUS GRANARIUS* DAMAGED BY ELEVATOR AND AUGER

D.A. Collins, T. Binns, D.A. Cook and S. Holloman.

Previous experiments have used an apparatus designed to simulate the forces of impact that occur during grain conveyance. However the results indicated no significant increase in insect mortality compared to undamaged insects, suggesting that the insects were little affected by the disturbance. Also the combined effect of physical disturbance and a low pesticide dose did not significantly increase mortality compared to the effect of the pesticide alone. These results suggested that the apparatus used did not cause any significant damage to the insects which would make them more susceptible to pesticide treatment. Therefore insects were collected from the farm-scale experiments for testing against insecticides, before and after conveying.

Aim

The aim of this experiment was to produce dose response data, using filter paper bioassays, for undamaged insects and for insects that had been put through an elevator conveyor and screw auger; to determine if any damage induced by the physical disturbance would enhance the effect of the pesticide treatment.

MATERIALS

Insects : Two lots of one tonne of grain were infested with approximately 8,000 adults of *Sitophilus granarius*. The insects comprised of 3 strains, the laboratory susceptible established in 1952 and 2 field strains collected from Hartlebury and Mamby in 1989. The insects were left to develop on the grain for 8 weeks to increase numbers and inter-breed, prior to testing.

Pesticide : A technical sample of pirimiphos-methyl was used for the experiment, at a purity of 88%.

Apparatus : A farm scale elevator conveyor and screw auger were used to produce the effects of physical disturbance (see Part 1).

METHOD

A wide 5-dose pesticide range from 1.299 - 26.3697 ug/cm^2 was selected as the insects were of mixed susceptibility. The amount of pesticide required was added to a mixture of 'Risella' oil, petroleum ether and acetone in a ratio of 1:3:1 by volume. 0.5 ml of the pesticide solution was applied to 'Whatman no. 1' filter papers. Nine replicate filter papers were set up for each dose. Also nine control papers were each treated with 0.5 ml of solvent only. These were then left to dry for 18 hours at 25°C and 70% rh. A glass ring coated with 'fluon' was then put onto each filter paper in order to confine the insects when added to the treated surface.

Prior to the grain being put through the equipment, samples were taken and the insects present were divided into 18 batches of 25. Three batches were added to 3 replicate filter papers of each dose including the control papers. These were classified as the undamaged insects.

One tonne of grain was then put through the elevator conveyor as described in Part 1. When the grain had passed through the equipment, samples were taken and the insects present divided into 18 batches of 25. Three batches were added to 3 filter papers of each dose including the control papers. The other tonne of grain was then put through the screw auger. The procedure was repeated and the insects added to the remaining filter papers. The insects were exposed to the filter papers at constant conditions of 25°C and 70% rh.

After 1 day exposure, the filter papers were examined and the numbers of live, knocked down and dead insects were recorded. The insects were then transferred onto clean filter papers, with a little kibbled wheat, and left for a period of 12 days. The numbers of live, knocked down and dead insects were then recorded. The results were subjected to probit analysis.

RESULTS AND DISCUSSION

The results of the probit analysis, after 1 day exposure, are given in Table 12. After the 12 day recovery period, probit lines could not be produced as the majority of insects had died. However where survivors did occur no significant difference between the types of disturbance was observed.

Putting *S. granarius* through an elevator conveyor and screw auger had little effect on their susceptibility to insecticide. The probit analysis showed there to be no significant difference in the mortalities of insects that were undamaged and those that were put through the elevator and auger. This indicates that the physical disturbance did not significantly increase insect mortality and that the mortalities observed were due to the effect of the pesticide treatment.

S. granarius is a relatively hardy insect, due to its compact shape and habit of pulling in its legs and antennae. A more susceptible insect such as *Oryzaephilus surinamensis* may be more effected by the physical disturbance induced by the elevator conveyor and screw auger.

Table 12
Dose response data for undamaged, elevated and augered *S.granarius*

Type of disturbance	KD/LD 50	95% limits	KD/LD 99.9	95% limits	slope	s.e	Chi-square	d.f.	p
Undamaged	1.91	1.73-2.09	6.55	5.18-9.39	5.76	0.66	2.50	4	0.65
Elevated	2.14	1.96-2.33	6.39	5.26-8.48	6.50	0.66	6.90	4	0.14
Augered	2.04	1.86-2.22	5.945	4.89-7.96	6.64	0.72	4.66	4	0.32

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