The detection of insects in grain during transit—an assessment of the problem and the development of a practical solution

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Abstract

Pest detection in grain, particularly during transit, is of great commercial importance. Most current methods will not detect insects at low population densities and often cannot estimate levels of infestation accurately. This limits management options and encourages the prophylactic use of pesticides.

Much research continues to be directed at improving methods of detection. However, the results so far either offer very limited improvements or require much more development before they are suitable for commercial application. Following a thorough review of the available options, it was concluded that some method of separating insects rapidly from large (5 kg or more) samples of grain, offered the most practical route to improved detection.

Prototype machines using sieves or aspiration to separate insects from grain were built and tested. The best results were obtained with a flat-bed, reciprocating sieve and development was concentrated on this design. The rate of flow of grain through the machine had a profound effect on the recovery of insects but the angle of the sieve and the amplitude of shaking had much less effect. The optimised prototype sieve was able to give consistent recoveries of two important species of grain pest close to 100%. Tests showed that this unit could process 10 kg of wheat in 1.8 minutes, recovering almost 100% of check insects in the grain. It proved capable of detecting infestations at population densities of 0.2 insects/kg and also gave reliable estimates of population densities.

Introduction

Rapid decisions must be made about the quality of individual lots or loads of grain, particularly during transit. The consistency and accuracy of such decisions will affect the price paid for the grain and will also influence the perceived value of the grain to the buyer. Often, the detection of insects will result in the rejection of a parcel of grain and will certainly affect the attitude of the buyer towards further storage or the need for treatment before storage. More importantly, failure to detect insects may lead to a load of infested grain being added to an otherwise uninfested bulk.

Currently, the majority of rapid assessments are based on the examination of a sample or samples. There are no internationally recognised methods, although several national bodies have well documented techniques for internal use. All seem to be based on the collection and examination of relatively small samples of grain (0.5–1.0 kg).

Work by Cogan and Wakefield (1987) suggested that, in small, 50 kg containers of grain, the likelihood of detecting insects by the collection of samples was a simple factor of the amount of grain removed and population density. However, Wilkin and Fleurat-Lessard (1990), working with artificially contaminated 20-t bulks of wheat, found that the removal and examination of samples will only detect insects with a high degree of probability when the number/kg exceeds five. The chance of detection was related to the population density and the number of samples or weight of grain that was examined. For example, only one 250 g sample in 80 contained an insect when the infestation rate was 0.2 insects/kg but rose to about 1 in 2 when the rate was 5 insects/kg. The basic conclusion of the work was that the standard approach to insect detection by sampling was extremely insensitive and was likely to miss substantial populations of insects, as well as underestimating the population density.

The aim of the work reported in this paper was to investigate the options for rapid detection of insects in grain and then, if possible, to develop a simple machine that would offer substantial improvements over current methods.

Current Approaches to Detecting Insects in Samples

It is widely recognised that examination of samples is an essential part of detecting insects in bulks of grain during transit and, to some extent, during storage. Therefore, the sampling technique is also likely to influence the effectiveness of detection (Hurburgh 1983; Wilkin 1991) but this was considered to be beyond the scope of this investigation. However, having obtained an appropriate sample, the effectiveness of the method of assessment will also be of great importance, both in terms of its ability to detect insects and its commercial acceptability.

Methods of detecting insects in samples of grain can be divided into two parts: novel approaches and mechanical separation.

Novel methods

There have been a number of research projects aimed at investigating methods of detecting insects in samples of grain. Several of these date back many years, but as yet, none seem to have been developed to a stage of commercial acceptability. Some of the more effective approaches are described below.

Detection of carbon dioxide

Insects respire and one of the by-products of respiration is carbon dioxide. Measurement of the carbon dioxide emissions from a grain sample can give an indication of the presence of insects and the level of infestation. The principles of the method were described by Howe and Oxley (1952), together with some of the advantages and disadvantages. Modern equipment offers the possibility of relatively rapid assessment of samples but only at the expense of costly and complicated

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apparatus (Bruce and Street 1974). It is also difficult to make the method work reliably with grain having a moisture content of about 15% or more, as the carbon dioxide produced by the grain may mask infestation. A final disadvantage is that at least five minutes per sample is required for an assessment.

Detection of uric acid

Uric acid is another by-product of insect metabolism which can be detected in a sample of grain (Wehling et al. 1984). However, this method requires expensive analytical apparatus and the results do not necessarily give an indication of current infestation. Uric acid is a relatively stable compound and may have accumulated in the sample over a period of time before analysis. Also the uric acid detected in the grain may have been produced by harmless, stray insects rather than damaging pests.

X-ray analysis of grain samples

Samples of grain can be examined by using X-rays and insects, particularly those hidden within grains, will show up (Fesus 1972). This method is used commercially in France by flour mills to examine samples of incoming grain. However, it requires expensive equipment, is relatively slow (about 30 minutes/sample) and will only work with very small samples of grain. Future development with equipment and perhaps image analysis technology could render this approach viable but this seems unlikely within the next five years.

Acoustic detection

Insects produce sound when moving and feeding in grain and this can be detected with sensitive equipment. Much research has been directed at this technique (Hagstrom 1990), with particular emphasis being placed on the use of microprocessors to differentiate between the sounds of insects and background noise. The general approach shows great promise but seems to be still some way from commercial application.

Nuclear magnetic resonance or near infra-red spectroscopy

Spectrographic examination of grain samples is already widely used in the grain industry to determine a number of quality parameters. Chambers et al. (1984) and Wilkin et al. (1988) demonstrated the potential of these techniques to detect insects and mites. However, there are some fundamental disadvantages associated with current analytical equipment, which limits the methods to working with small samples of grain (100 g). A major breakthrough in either the equipment or its method of use will be required before these methods can be considered as having potential for commercial use.

Extraction of insects with Berlese-type equipment

Live insects can be persuaded to leave a grain sample by the application of dry heat. The Canadian Grain Commission uses this technique to check some samples of grain collected during an annual audit process. Smith (1977) demonstrated that the method was effective with dry grain (<14%) but recovered less than half the insects from grain with a moisture content of 16%. It uses relatively simple equipment and could work with large samples of grain, but is unsuitable for rapid assessments.

Mechanical separation

Despite the work reported above, sieving a sample of grain to remove insects, or some other form of physical separation, is by far the most widely used method and would appear to offer the greatest potential for the speedy development of an improved approach to detection. Surprisingly, little research has been carried out on this topic, perhaps because of its apparent simplicity.

Sieving relatively small (250 g–1 kg) samples is by far the most widely used method of detecting insects in grain, both in the U.K. and on a worldwide basis. The Canadian Grain Commission, the Australian Wheat Board and the U.S. Federal Grain Inspection Service all rely on sieving numerous, relatively small samples of grain to detect insects. None of these bodies quotes any scientific research to support the method of sieving that is recommended, although methods of sample collection are carefully prescribed.

Unpublished work by Goodman (1979) suggested that manual sieving was not entirely reliable in removing insects from samples of grain. It is extremely surprising that there does not appear to be any published data on this topic, despite the widespread, international use of the technique.

Sieving of larger samples has been recognised as a method of improving the detection of insects in grain. White (1983) describes an inclined plane sieve for use with 25 kg samples. However, tests of the efficacy of this simple device suggested that up to seven passes down the sieve were needed to recover all the test insects seeded into a sample. This would indicate that a simple sieve may not provide the complete answer to the problem of detection, irrespective of the size of samples that are used.

Summary

The following conclusions can be drawn from the above review of available methods:

- Insect detection is inextricably linked to the amount of grain that is examined, regardless of the method used. However, commercial constraints limit the amount of time that can be spent examining samples.
- The commercial options for the rapid assessment of large samples of grain for the presence of insects are limited.
- Much recent and current research on the topic seems to be aimed at developing methods that are not suitable for the rapid assessment of large samples or are still some way from commercial application. In addition, some of the methods will require the use of expensive equipment.
- Mechanical separation (sieving or aspiration) seemed to offer the best option for rapid detection of insects in large samples of grain.

Investigations and Development Work

Assessment of manual sieving

Despite the widespread use of manual sieving, there are no data to confirm that it is an effective method of removing insects from grain. Therefore, a small experiment was done to assess the efficiency of manual sieving in removing insects from samples of grain under controlled conditions. In general, this was based on the procedures used to assess grain offered for sale into the U.K.

Materials

English wheat of unknown origin and a moisture content of about 13% was used as the substrate. This grain was divided into 500 g batches and live, adult *Oryzaephilus surinamensis* or *Sitophilus granarius* of unknown age and sex, were collected from laboratory cultures and added to the samples. These samples were then sieved over a 200 mm diameter sieve of the type recommended by the Intervention Authorities, with a 2 mm stainless steel mesh.

Methods

Insects were added to the batches of grain at rates of 1/sample and 5/sample and each species was assessed separately. The insects were allowed between 5 and 10 minutes to disperse before sieving commenced. In all but one case, five replicate samples were used with each density and species. Exceptionally, in one case 10 replicates were used.

Each infested sample was tipped into the sieve and shaken by the same operator for 30 seconds. The sievings in the receiver were examined and the number of insects recorded. Batches of grain to which no insects had been added were assessed in the same way to confirm that the grain was uninfested.

Results

Complete recovery of *S. granarius* was obtained at both rates of inclusion. Complete recovery of *O. surinamensis* was obtained at 5/sample and in 9 out of 10 replicates at 1/sample.

Conclusions

Given conditions as described, manual sieving should detect the presence of either of the two species in a sample without difficulty. It should also allow the population density within the sample to be estimated with a high degree of precision. Therefore, any new device must aim to offer a similar level of effectiveness.

Production of prototypes

When options for prototype machines were considered, certain constraints had to be applied to limit the range of designs that could be considered. These constraints included, likely cost of the final machine, ease of manufacture and, most importantly, ease of use. Three options were considered: a rotating drum sieve (Fig. 1); a zig-zag aspirated separator (Fig. 2); and an eccentric, reciprocating table sieve (Fig. 3). Working prototypes of all three machines were built and tested.

Testing of prototypes

Initially, all prototypes were tested for their ability to remove fine material from 10 kg batches of grain. The two sieve based separators gave broadly similar results but the aspirated separator removed almost twice as much material. This was because it was also removing some small and light grains that were not separated by the sieves.

For the second series of tests, 50 dead adult *S. granarius* were added to the 10 kg batches of wheat that had been cleaned. About 50% of the insects were recovered using the table sieve, none were recovered with the rotating drum sieve and about 25% with the aspirated separator. However, with the latter machine the insects were recovered as fragments.

Some time was spent investigating the performance of each machine and assessing the effects of modifications. The poor performance of the rotary sieve appeared to be related to the relatively small area of sieve that was in contact with the grain at any one time. Using very slow rates of throughput and internal baffles allowed this unit to recover some insects but never as many as the other sieve. Therefore, the rotating drum sieve was abandoned.

The number of insects recovered by the aspirated separator could be increased by careful adjustment of the rate of airflow but some of the dead insects were still being damaged by passage through the machine. It is possible that live insects would not have been damaged to the same extent. Difficulties were also encountered in adjusting the airflow and obtaining consistency between samples. It was, therefore, decided to abandon this approach.

Work on the reciprocating sieve showed that recovery could be improved by reducing the depth of grain flowing over the sieve, and up to 75% of dead *S. granarius* could be separated from the grain in a single pass. Further development work was concentrated on this machine.

Modifications to the reciprocating sieve

The rate of flow of the grain through the sieve and the depth of grain on the sieve plate affected the recovery of insects, with slower, thinner flows giving best results. However, even at the slowest flow rates, recovery of dead insects was not as good as obtained with the hand-operated sieve. Amplitude of shaking and inclination of the sieve plane had relatively little influence on the rate of recovery.

Initially, the machine used a 2 mm, round hole sieve plate and the area of these holes was smaller than the area of the

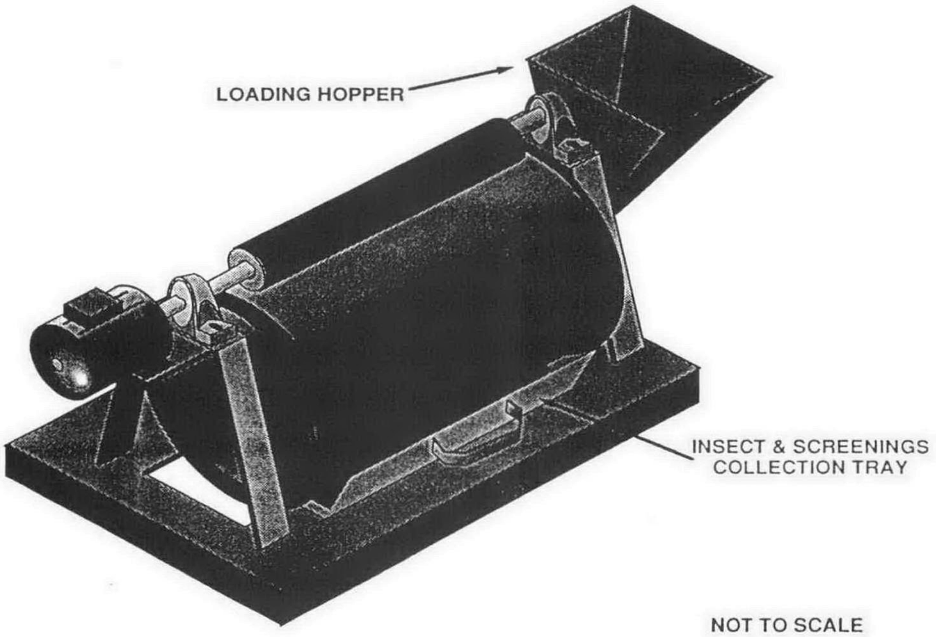

Fig. 1. Rotating drum sieve.

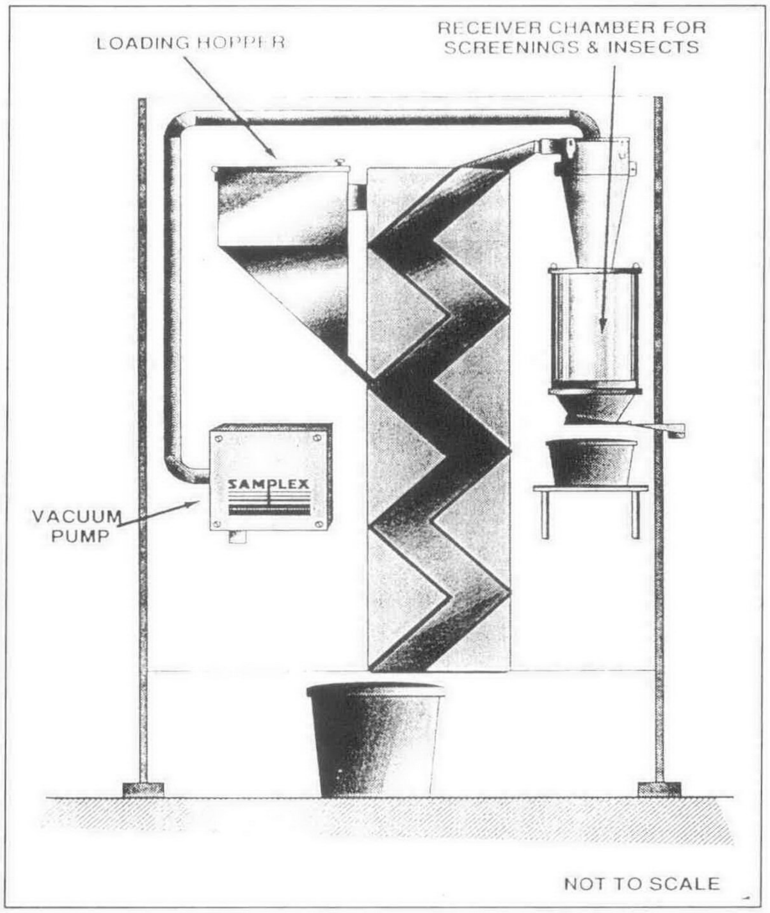

Fig. 2. Zig-zag aspirated separator

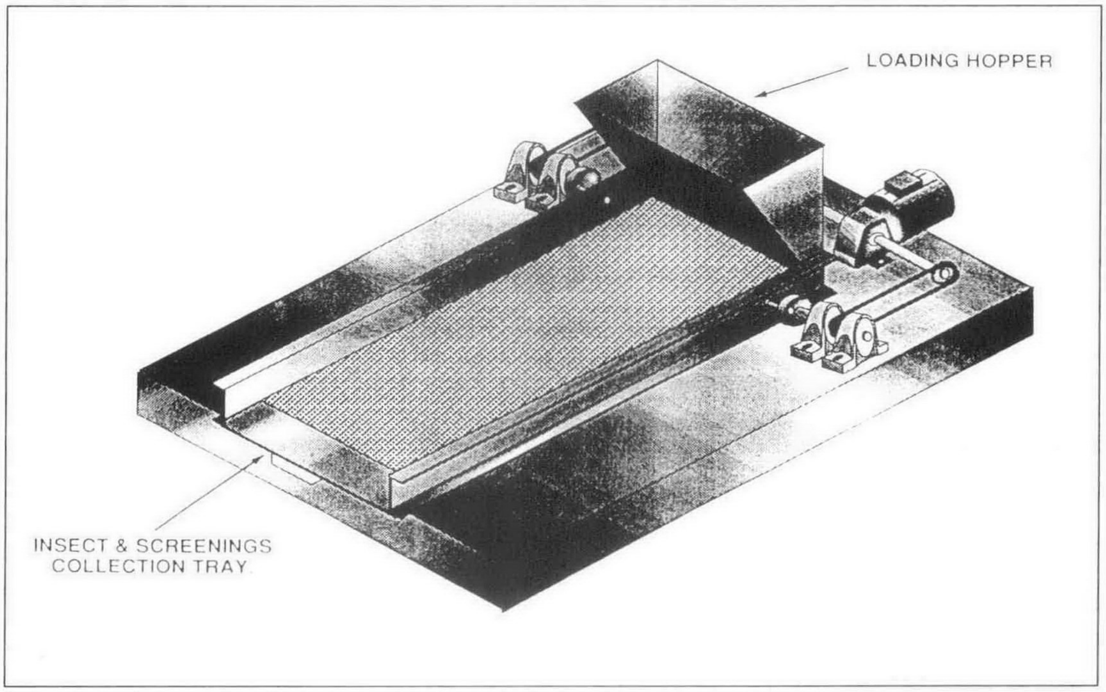

Fig. 3. Eccentric reciprocating table sieve.

apertures in a 2 mm mesh sieve. For mechanical reasons, meshes are less satisfactory than perforated plates in mechanised sieves. Therefore, a sieve plate with a 2.5 mm round hole was substituted. This produced an immediate improvement in recovery to almost 100% and allowed the rate of throughput to be increased, giving a time to sieve 10 kg of less than 2 minutes.

A full assessment of this machine was then done using live insects. Ten live adult *S. granarius* or *O. surinamensis* were added to 5 kg samples of wheat and each sample was passed through the machine three times. Three replicate samples were tested for each species. Between 80 and 90% of the *S. granarius* were recovered on the first pass and 100% were recovered by the third pass. Complete recovery of *O. surinamensis* was achieved on the first pass. A further, replicated test with *S. granarius* was carried out with two insects added to each 5 kg sample. Complete recovery was achieved on the first pass.

A final test was carried out in which the 10 adults of both species were added to 5 kg samples of wheat and allowed 24 hours before the samples were sieved. Between 80 and 100% recovery of both species was obtained on the first pass. However, total recovery was not achieved in every case, even after three passes through the machine, and it is possible that some insects had escaped from the grain.

Development and Testing of a Pre-production Prototype

The prototype machines had been built to test the principles involved, but did not address the needs of operating under practical conditions, nor did they incorporate all of the features which were likely to improve the ability of a sieve to recover insects. Any practical machine must be easy to use and safe, as well as being effective. Ease of use must include features such as ease of loading, simplicity of operation, ease of cleaning and low noise level.

A machine was constructed, incorporating the basic features of the prototype, flat-bed sieve, but taking account of the requirements for safety, ease of use and incorporating features that were likely to optimise efficiency. The machine was constructed in stainless steel, although a final production version may use other materials (Fig. 4). The main sieve was a flat plate with 2.5 mm holes (Fig. 5), although an option was included to incorporate two sieve plates of different meshes. The sieves were easily detachable for cleaning (Fig. 6). The insects and sievings were collected in a removable receiver (Fig. 7).

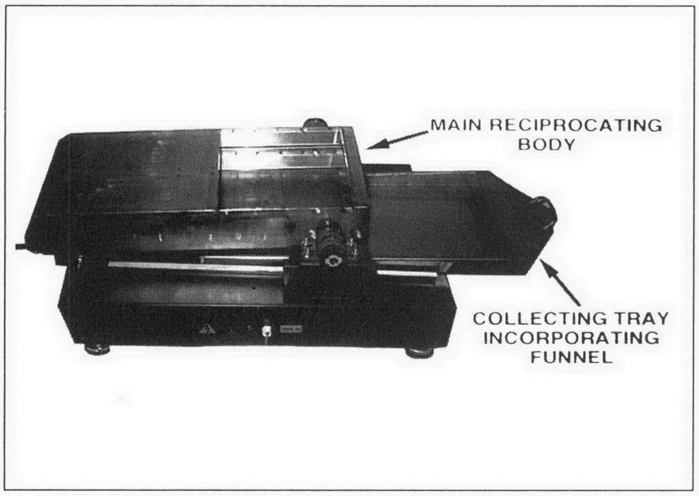

Fig. 4. Pre-production prototype reciprocating sieve.

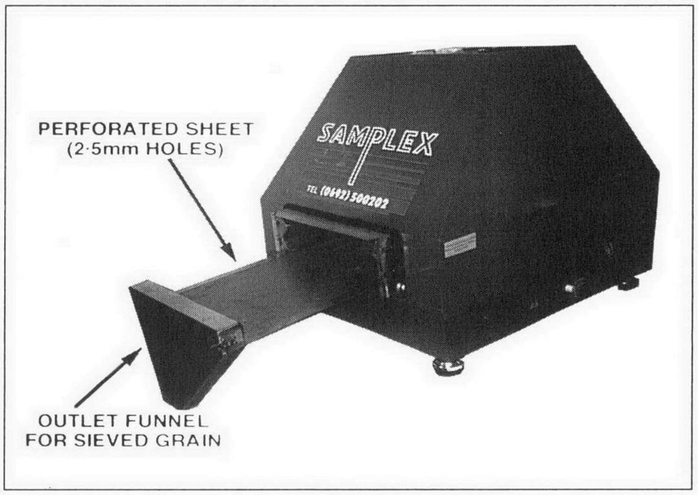

Fig. 5. Pre-production prototype reciprocating sieve, showing flat plate with 25 mm holes.

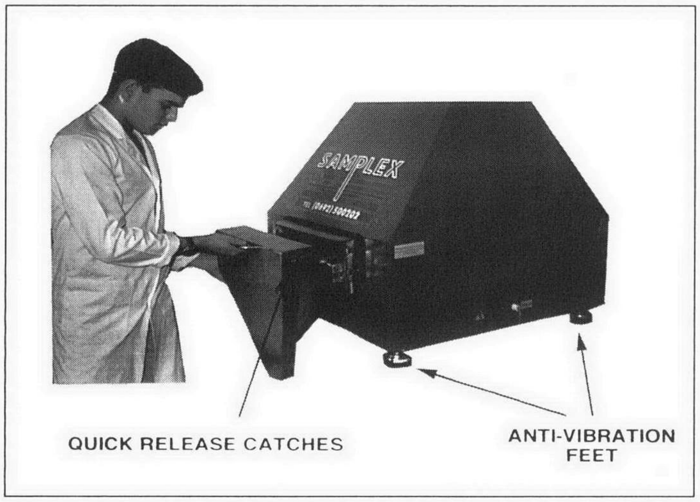

Fig. 6. .Pre-production prototype reciprocating sieve, showing detachable sieves.

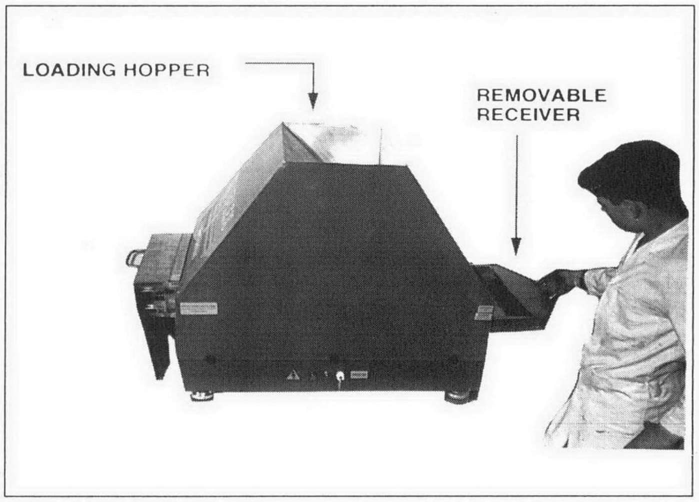

Fig. 7. Pre-production prototype reciprocating sieve, showing removable receiver.

Table 1. The mean recoveries of insects from 5 kg samples of wheat or barley using the final prototype reciprocating sieve. Each test result is the mean of three replicates.

Test no.	Conditions of test	Percent recovered on first pass	
		S. granarius	*O. surinamensis*
1	10 live insects/5 kg wheat	97	–[a]
2	As above, insects left on grain for 5 minutes before sieving	100	–[a]
3	1 live insect/5 kg wheat	100	–[a]
4	10 live insects/5 kg wheat	–[a]	100
5	1 live insect/5 kg wheat	–[a]	100
6	100 live insects/5 kg	–[a]	97
7	5 live insects of each species/5 kg of barley	107[b]	173[b]

[a] No insects of this species were included in the test.

[b] The barley was used 'as supplied' by a merchant and was already infested with both species of insect used in the tests. Assessments of the grain without additional insects confirmed that the results in the table reflected the inherent infestation in the barley plus the test insects.

A detailed test program was undertaken to confirm that this machine would extract insects from grain at least as well as the first prototype and also to confirm that it was easy to use.

Test procedures

English wheat of unknown origin was used for most of the tests but English feed barley was used in one case. Initial tests were with dead insects but then live insects were substituted. Adult *O. surinamensis* or *S. granarius* taken from laboratory cultures were used. Five-kg samples were used for all tests and each sample was passed through the machine up to three times or until all insects were recovered. For each test, three replicate batches were used. For initial tests, the flow rate through the machine was 5 kg/30 seconds. Subsequently, the rate was reduced to 5 kg/50 seconds.

Results

The initial tests with dead insects and a rapid flow rate gave a mean recovery rate for 10 dead *S. granarius* of 87% on the first pass. A further 10% was recovered during the second pass and the final 3% of the insects were recovered on the third pass. When the tests were repeated with the slower flow rate, 100% of the *S. granarius* were recovered on the first pass. The rates of recovery at the slower flow rate are summarised in Table 1.

The recovery rate of insects in the above tests was always high and the insects appeared undamaged and were still alive after extraction. When the recovery was less than 100%, the missing insects were almost always recovered by passing the grain through the machine a second time. Stripping down and cleaning the machine failed to yield any insects lodged in the sieve or hopper system.

A further series of tests were done using grain containing about 2% screenings. This did not affect the recovery rate but did slow the final assessment as the insects were somewhat more difficult to spot in the receiver.

Conclusions

An assessment of the options available for the rapid detection of insects in grain during transit, suggests that whatever method is used, it must be capable of dealing with multi-kilogram samples if the low population densities are to be detected or estimated accurately. The mechanical separation of insects from samples of grain was chosen as the most appropriate method for the development of a machine that could be produced and offered for sale within a limited time period.

The pre-production prototype, flat-bed, reciprocating sieve that was developed during this project is able to process large samples of grain rapidly (10 kg of wheat/1.8 minutes). It is able to detect reliably two important species of grain pest at population densities of 0.2 insects/kg. This is comparable to the population densities detected by trapping methods used during storage and is greatly superior to the level of 2–5 insects/kg detectable with current, commercial sampling and sieving methods. The test results from this machine also show that it was possible to estimate the population density to a high degree of accuracy. The pre-production prototype appears to meet all requirements for ease of use and safety, and would appear to be well suited for use in a commercial grain laboratory.

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