**MINISTRY OF AGRICULTURE, FISHERIES AND FOOD** **CSG 15**

Research and Development

# Final Project Report

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## Executive summary (maximum 2 sides A4)


Demand for organic grain continues to grow and currently in the UK much has to be imported to satisfy the market. Expansion of UK production, together with continued imports, will see an increase in the need for effective grain storage using organic methods to preserve the quality of this valuable commodity. The objectives of this project were to conduct a desk study review to:

1) Highlight the main grain storage problems experienced by organic growers in the UK.
2) Bring together in a more convenient form technical information already available that will enable growers to tackle these problems more successfully.
3) Identify areas of current storage technology requiring a minimum of modification to ensure a smooth transfer from the conventional to the organic sector.
4) Identify areas where appropriate organic alternatives to conventional storage procedures do not exist that will require further research and development to find replacements.

**1) Problems associated with storing organic grain**

Grain storage facilities on six organic farms were inspected, and discussions were held with organic farmers and millers, together with representatives from the Soil Association and the Henry Doubleday Research Association. The main problems associated with storing organic grain, namely the prevention of attacks by pests and moulds, were similar to those experienced by conventional growers but with the additional constraints of avoiding the use of pesticides. Insect and mite pests detected were similar to those found in conventional grain, while beneficial species, particularly the mite *Cheyletus eruditus* which preys on pest species, were much in evidence. Trade rejections due to pests and moulds were generally low, probably because in the past most organic grain was stored for less than six months, allowing time for store cleaning and a break in the food supply for pests. If storage periods lengthen pest infestation will increase, particularly since regular monitoring for pests, moisture content and temperature was rarely practised.

**2) Information sources for organic grain storers**

A review was conducted of the technical information sources currently available on organic grain storage strategies; this confirmed the need for an up-to-date information source. It was decided to develop an 'Organic Module' for the Integrated grain Store Manager (IGSM) decision-support software package. A technical article on the findings of the project, together with practical advice on grain storage, has been written for publication in the 'Organic Farming Journal'. Material has been prepared for a Soil Association workshop and an Elm Farm Research Centre Network Event. A booklet on the more technical aspects of the organic storage of grain has also been produced which will join the series of Technical Guides published by the Soil Association.

**3) Pest management strategies for organic grain storage**

The review went on to consider areas of commonality and conflict between conventional and organic approaches to grain storage, and the alternatives to the use of pesticides and fumigants that are currently available or that will require only a minimum of modification to attain organic approval. In particular the need for organic alternatives in four areas were identified:

- Grain store structure treatments.
- Admixture chemicals for prophylaxis and control of infestation in grain.
- Top dressing of cooled bins as part of an integrated pest management strategy.
- Fumigation for prophylaxis and treatment of infestation.
- Vertebrate pest control.

The main keys to the safe storage of organic grain were identified as:

- Preparing the store well by excluding vertebrate pests, and cleaning residues that may harbour invertebrate pests that will infest the grain as it enters the store.
- Drying the grain as it comes off the field to prevent mould and mite increase and to preserve market qualities such as germination.
- Cooling the grain to protect against insect invasion and to preserve quality.

Since fumigation and pesticide admixture are not an option for organic grain, it is even more important that store hygiene, grain drying and cooling are carefully and successfully carried out and that the grain is regularly monitored for pests and moisture content to avoid pest and mould problems. A number of currently untried and/or unregistered remedies for infestation may eventually become available to organic farmers, including the use of diatomaceous earths, biological control, and dryers and cleaners to disinfest grain.

**4) Opportunities for improving organic grain storage**

The following have been identified as areas requiring further research and development that are likely to provide important opportunities for improving the storage of organic grain:

- Store structure cleaning, including the effectiveness of vacuum cleaning and steam treatments, and the feasibility of using diatomaceous earths to control invertebrate pests.
- Energy efficient drying and cooling systems, and consider the use of renewable energy sources including solar and wind power or the processing of waste products and energy crops.
- More effective invertebrate pest monitoring through improvements in sampling strategies, together with enhanced trap design and the incorporation of lures.
- Disinfestation using grain cleaners and hot air driers.
- Biological control for store structure treatments. This will require work to assess the effectiveness of naturally occurring biological control agents to treat residual infestations hidden in empty grain store structures. Strategies will need to be developed to encourage the development and conservation of beneficial invertebrates in stores, including the possible use of natural semiochemicals to manipulate their behaviour.
- Biological control for surface infestations of grain. As well as looking at the practicality of using top-dressing or bait trap application techniques to control grain surface infestations in cooled bins, there is a need to develop effective methods for the removal of beneficial invertebrates from the grain immediately before it is marketed.

## Scientific report (maximum 20 sides A4)

## Introduction

Cereals and oilseeds are one of the largest groups of crops produced organically, with 33,500 tonnes grown in the UK during 1998/99 and worth over £6 million; however, demand for organic grain is increasing annually and around 60% has to be imported (Soil Association, 1999). Expansion of UK production, together with continued imports, will see an increase in the need for effective grain storage using organic methods to preserve the quality of this valuable commodity.

Stored grain is at risk from attack by insects, mites and moulds. Even when pest-free grain is brought into store it may be attacked by pests already present, hidden in the fabric and structure of the building. Conventional storage practice relies heavily on the use of organophosphate pesticides for grain protection (Norris and Garthwaite, 1997). Organic storage avoids the use of pesticides but there is no reason why organic storage methods should be any less effective than conventional techniques.

The objectives of this project were to conduct a desk study review to :
1) Highlight the main grain storage problems experienced by organic growers in the UK.
2) Bring together in a more convenient form technical information already available that will enable growers to tackle these problems more successfully.
3) Identify areas of current storage technology requiring a minimum of modification to ensure a smooth transfer from the conventional to the organic sector.
4) Identify areas where appropriate organic alternatives to conventional storage procedures do not exist that will require further research and development to find replacements.

## Objective 1. Highlight the main post-harvest problems experienced by organic grain growers in the UK.

Objective 1 has been met in full. Grain storage facilities, ranging in capacity from 1000 tonnes down to 30 tonnes on a sample of organic farms were inspected, and discussions were held with organic farmers, grain merchants and millers, together with representatives from the Soil Association and the Henry Doubleday Research Association. Grain quality requirements and the UK organic grain market were also considered.

### Problems identified

From our inspections of the fabric, equipment and grain in stores used for organic grain on six farms in the UK between June and August 1999, storage mites and secondary insect pests were the commonest invertebrates found although one farm had a significant infestation of the primary insect pest, the saw-toothed grain beetle (Table 1).

**Table 1. Invertebrate pests detected in stores used for organic grain on six farms.**

| Order/Family | Scientific name | Common name | No. of farms |
|---|---|---|---|
| **Astigmata** | | | |
| Acaridae | *Acarus siro* | Flour mite | 3 |
| | *Acarus farris* | | 1 |
| | *Glycyphagus domesticus* | House mite | 1 |
| | *Lepidoglyphus destructor* | Cosmopolitan food mite | 2 |
| | *Tyrophagus longior* | Grainstack mite | 2 |
| | *Tyrophagus palmarum* | | 1 |
| | *Tyrophagus* spp | | 1 |
| **Coleoptera** | | | |
| Cryptophagidae | *Atomaria* spp | | |
| | *Cryptophagus acutangula* | Mould beetle | 1 |
| | *Cryptophagus* spp | Mould beetle | 1 |

| | | | |
|---|---|---|---|
| Dermestidae | *Anthrenus fuscus* | Carpet beetle | 1 |
| Endomychidae | *Mycetaea hirta* | Hairy fungus beetle | 1 |
| Lathridiidae | *Dienerella ruficollis* | Plaster beetle | 1 |
| | *Lathridius minutus* | Plaster beetle | 2 |
| | *Lathridius pseudominutus* | Plaster beetle | 2 |
| Nitidulidae | *Meligethes* spp | Blossom beetle | 1 |
| Silvanidae | *Oryzaephilus surinamensis* | Saw-toothed grain beetle | 1 |
| **Lepidoptera** | | | |
| Oecophoridae | *Endrosis sarcitrella* | White-shouldered house moth | 3 |
| | *Hofmannophila pseudospretella* | Brown house moth | 1 |
| **Psocoptera** | | | |
| Trogiidae | *Lepinotus patruelis* | Black domestic psocid | 5 |
| | *Lepinotus reticulatus* | Black domestic psocid | 1 |

Primary pests are those specially adapted for the grain storage environment and able to breed in grain of low moisture content while secondary pests only attack grain that is poorly conditioned, damp or already infested. Beneficial invertebrates that attack storage pests were also present on all farms (Table 2).

**Table 2. Beneficial invertebrates detected in stores used for organic grain on six farms.**

| Order/Family | Scientific name | Prey Species | No. of farms |
|---|---|---|---|
| **Coleoptera** | | | |
| Carabidae | *Stomis pumicatus* | General predator | |
| Staphilinidae | *Datomicra zosterae* | General predator | 1 |
| | *Oligota* spp | Storage mites | 1 |
| | *Xylodromus concinnus* | General predator | 1 |
| **Prostigmata** | | | |
| Bdellidae | *Spinibdella* spp | Storage mites | 1 |
| Cheyletidae | *Cheyletus eruditus* | Acarid mites, psocids, young stages of storage beetles and moths | 5 |
| | *Cheletomorpha* spp | Acarid mites | 1 |
| Erynetidae | *Erynetes* spp | Mites | 1 |
| **Mesostigmata** | | | |
| Ascidae | *Proctolaelaps pygmaeus* | Mites | 1 |
| Dermanyssidae | *Androlaelaps casalis casalis* | Acarid mites, young beetle larvae | 1 |
| Haemogasmasidae | *Haemogamasus pontiger* | Astigmatid mites, young stages of storage insects | 2 |
| Macrochelidae | *Macrocheles* spp | Storage insects | 1 |

The presence of pest mites, psocids and moths indicates a contamination risk for organic products just as it

does for conventional ones. All of these, particularly mites, have allergenic properties and there might be health consequences where cereal products are destined for human or animal consumption. The situation is exacerbated by the low frequency of monitoring for pests and physical condition (Table 3), particularly since the success of non-chemical storage largely lies in monitoring physical conditions.

**Table 3. Some responses to key questions by 6 organic farmers.**

| Farm no. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| **Organic grain capacity (t)** | 80 | 30 | 60 | 600 | 750 | 1000 |
| **Type** | Bins | Bins | Bins | Bins | Floor | Floor, bins |
| **Use** | Milling, seed | * | Feed, milling | Milling | Milling | Milling wheat feed barley, seed, sprouting |
| **Storage period** | Till February | * | Oct- Jan. | Till end May | Wheat - till May | Till May - June |
| **Pests / problems** | Rodents, birds | * | Rodents, birds | Dust | Rodents, dust | Insects, mites, rodents, dust |
| **Organic/ convention-al mixed** | Yes | * | No | Yes | No | Yes |
| **Equipment** | Drier with cooling section, cleaner | * | Drier, cleaner | Dryer, cleaner, aeration | Dryer, cleaner, aeration | Dryer, cleaner, aeration |
| **Hygiene** | Vacuum | * | Vacuum, brush | Vacuum, brush | Vacuum, brush | Vacuum, brush, Pyrethrum spray |
| **Rejections** | 0 | * | 1- admixture | 0 | 0 | 0 |
| **Monitoring** | PC traps | * | No | No | No | Temps, MCs |
| **Advice** | Fellow farmers, merchants, millers, ‘The Farmers’ Handbook’ | * | Organic farming advisor | | Ag. shows | Own experience, convention -al farming literature |
| **Computer** | Yes but prefers hard copy | * | No | Yes Internet access | Yes | Yes but would not buy software |

* Farmer unable to supply information in time for this report.

Organic grain is usually cleaned before marketing and, possibly as a result, appears rarely to have been rejected by millers on the grounds of insect or mite infestation. While such cosmetic operations do much to clean up or disguise infestation, they do not affect pests hidden inside the grain or necessarily remove completely the allergenic waste products of pest activity; after this operation pest populations can build up quickly to original levels. However, with the improved standards of pest control required by the amended Food Safety Act and the Assured Combinable Crops Scheme, more effort will be needed to reduce pest levels in the first place.

During our visits farmers expressed a desire for more advice and information, on the following topics:-

A. Store preparation and monitoring.
1) The timing and most appropriate non-chemical methods for cleaning store fabric prior to intake of newly harvested grain, to ensure residual infestations are removed. Design of cleaning equipment to tackle store areas with difficult access.
2) The best means of monitoring for residual infestation hidden in the fabric of empty stores.
3) How to tackle the problems associated with poorly constructed or maintained grain stores, such as fabric cleaning, bird and rodent proofing, to help ensure that organic grain achieves standards equivalent to those of the Assured Combinable Crops Scheme.
4) How to deal with the risk of cross infestation from other infestable commodities such as animal feed, legumes, straw and hay.
5) The sources of insect and mite pests that lead to the infestation of newly harvested grain.
6) Design of storage buildings and equipment, particularly to improve access for cleaning and to prevent dust from dryers and grain movement collecting in the store fabric.

B. Grain treatments.
1) The optimum rates for grain drying and cooling, together with the most energy-efficient strategies.
2) Alternatives to conventional pesticides for use when pest numbers reach unacceptable levels, such as grain turning and augering, the use of inert dusts and low oxygen atmospheres.
3) The most effective methods for grain cleaning to remove contaminants such as pests and weed seeds, particularly prior to marketing.
4) How to deal more effectively with the problems caused by dust arising from grain handling, cleaning and drying, particularly as protective clothing was often uncomfortable to wear.

**C.** Monitoring of pest and grain condition.
1) The most effective traps and other pest monitoring aids.
2) Guidelines for the positioning and number of traps/sampling points for accurate monitoring.
3) Choice of instruments for measuring grain temperature and moisture content, and frequency of monitoring.

**D.** Pest and store management.
1) The  management of the storage environment to minimize the risks of infestation.
2) Manipulation of the storage habitat to encourage naturally occurring predatory species and other beneficial organisms to control pests.
3) Identification guides to help with distinguishing between pest and beneficial species.
4) Techniques for retaining beneficial species when cleaning out stores to remove residual pest populations.
5) The best methods for ensuring beneficial species do not contaminate the grain when it leaves the store.
6) Strategies for keeping grain pest-free during long term storage was another area of concern for the future, including the frequency of monitoring.

**Quality requirements and the UK organic grain market**

Representatives of grain merchants and animal feed merchants were contacted for information on quality requirements for organic grain. On the whole, similar standards of quality are expected and accepted for organic grain as for conventional, including the same levels of moisture content, insect and weed contamination. However, there is a degree of flexibility in what the grain merchants and end-users will accept. The quality of the grain fluctuates with the growing season, as does the price of imported grain, and this has to be taken into

account by the buyers. Sometimes a higher percentage of screenings and contamination by weeds is accepted. The main problem associated with organic milling wheat is low protein content which affects milling quality and tends to be lower than in conventional wheat. Protein content is governed by factors such as the growing conditions of the season and soil fertility, not by storage conditions. Protein content of organic grain should normally be greater than 10.5% (Lampkin and Measures, 1999) but, depending on the year, sometimes percentages as low as 9% are accepted for milling. As with conventional grain, however, the price achieved for the grain drops by about £1/tonne for each 0.1% fall in protein content. The bread making quality of wheat is affected by its content of the enzyme alpha amylase. Hagberg numbers, a measure of this enzyme, are usually required to be 250 or greater for both conventional and organic wheat. Similarly, bushel weights of 76kg/hl are normally required for both types of cereal.

Standard requirements for organic feed wheat are similar to conventional feed grain, that is 72kg/hl bushel weight and a maximum moisture content of 15%. One feed merchant reported that the quality of organic wheat for feed was usually better than that of conventional because organic farmers tended to grow milling varieties, with their higher protein contents, in the hope of obtaining a higher price for milling grain, and then fell back on the feed market if the protein content was not adequate. Organic grain also tended to be cleaner, presumably because it is a higher value crop than conventional, and is handled and cleaned more carefully. The bushel weight also tends to be higher for organic grain.

**Rejection rate of organic grain**

Organic grain is rarely rejected by millers and feed merchants. The most common causes of rejection are weed contamination and/or moisture contents higher than 15%. Rejections due to insect contamination are even less common but there have been some cases of weevil or mite infestations (Starling, W. *pers. comm.*). Even when rejections do occur it is hardly ever the case that the grain is beyond redemption; it can be cleaned, screened or dried to achieve the required standard. It is not unheard of for the screenings and weed seeds to be used for organic poultry feed but this is usually used on the farm producing the grain. Five millers and merchants were asked if there were any problems with organic grain that they felt needed addressing in terms of more careful storage and handling by the farmer. All said that there were no particular problems at present.

**The market for organic grain**

The market for organic barley is less well developed than for wheat or oats but there is increasing demand for organic feed barley because of the expansion of the organic livestock sectors and the tightening of the organic standards which demand a higher proportion of organic feed (Lampkin and Measures, 1999). Approximately 90% of organic farmers who grow grain produce it for their own livestock feed (Bevan *et al.*, 1997). The market for malting barley and flaking barley for muesli is limited (Lampkin and Measures, 1999). In the past most organic milling grain used in the UK was imported from Australia, and the price of this grain tended to dictate the price achieved for UK grown grain. Now that the supply of UK organic cereals and other arable crops is set to increase over the next few years the supply of grain needs to be managed carefully. Recently the "Organic Arable Marketing Group" (OAMG) was set up by a group of experienced organic farmers brought together by Elm Farm Research Centre (Burke, 2000). Farmers who trade their arable crops through the group will be able to become shareholders and benefit from the profits generated. The OAMG seeks to achieve market stability, optimal prices and a profitable operation. The approach to achieve this objective is to develop long-term relationships with customers so that supply can be well organised and targeted to specific outlets.

In December 2003 it is expected that the EU derogation which permits the use of non-organic seed will end. Farm-saved seed may become an option but much more care is required for the storage of seed, so specialist storage facilities may be required.

**Compatibility of organic standards with assured quality schemes**

The UK organic food standards (UKROFS) require organic farmers to keep records of inputs such as fertiliser and pesticide applications, and all produce has to be traceable. Organic farmers are subject to the same legal obligations on the handling of pesticides as conventional farmers. In many cases, principles set down in MAFF codes of practice also have to be complied with. For example, effluent from silage and slurry must not be allowed to enter waterways.

Since 1995 all grain stores containing cereals intended for human consumption have been designated as food premises under the Food Safety Act (Anon., 1990); now all these grain stores are subject to inspection to ensure that adequate pest control measures are in force and are maintaining an appropriate level of control. In response to this and other factors, such as public concern about pesticide residues in food, the UK cereals industry has set up the Scottish Quality Farm Assured Cereals (SQFAC) and the Assured Combinable Crops Schemes (ACCS) (Anon., 1997a; 1998). These schemes are based on the principle that the industry will only use products and methods that are recognised as "Best Practice". The spirit of the organic standards has a lot in common with that of ACCS and SQFAC schemes. However, in order to register with these schemes organic farmers would have to keep many more records, such as for maintenance and cleaning of farm machinery, equipment and stores, in addition to those they compile for UKROFS. This extra record keeping may deter many organic farmers from joining the new schemes.

When some organic farmers were approached, they indicated that they were keen for organic cereals to reach equivalent standards of quality and hygiene as ACCS/SQFAC grain. Their main concern was that organic grain could not be produced according to these standards because the farmers' interpretation of them was that grain would have to be treated with pesticides. However, there is no such requirement specifically mentioned in the ACCS/SQFAC regulations; on the contrary, they actually recommend that prophylactic pesticide applications should be avoided and other chemical treatments should only be used "where appropriate". So there appears to be nothing to prevent organic farmers joining the schemes if they wish.

## Objective 2. Bring together in a more convenient form technical information already available that will enable growers to tackle these problems more successfully.

Objective 2 has been met in full. A review was conducted of the information sources currently available to farmers on organic grain strategies.

**Information sources on conventional grain storage.**

There are few up-to-date, thorough and dedicated information sources on UK grain storage. The two currently available are the decision-support computer software ‘Integrated grain storage manager’ (Knight *et al.,* 1997) and the ‘Grain Storage Guide’ (Armitage *et al.,* 1999). The latter is also accessible on the internet at:

http://www.hgca.com/research/grainstorage/

Both of these were part-funded by the Home-Grown Cereals Authority (HGCA) and based on earlier research funded by the Pesticide Safety and the Cereals and Set-aside Divisions of MAFF. HGCA also issues ‘Topic sheets’ (eg. Anon, 1997) which offer new advice based on research that they have funded.

**Information sources on organic grain storage.**

There is even less information available on organic grain storage that is readily available to farmers. For example, the "Organic Farm Management Handbook" (Lampkin and Measures, 1999) is widely purchased by organic farmers but devotes only 4 lines to grain storage. A recent MAFF-funded review on the storage of organically produced crops (Bevan *et al.,* 1997) identified only two short articles on grain storage in the organic farming press (Starling, 1996; 1997). Different types of store and the control of the store environment are addressed in the review, together with an economic analysis of organic grain storage based only on the two seasons of data available at the time. However, the review is not in a user-friendly form for farmers.

During the present study a few additional sources of information on organic grain storage have been identified. The Elm Farm Research Centre Bulletin has produced two brief articles for farmers on grain storage. The first sets out organic standards associated with cleaning stores, keeping organic grain separate from conventional grain, and a few technical points on grain storage (Bulson, 1993). The second article, based on the economic analysis detailed in the MAFF-funded review mentioned earlier, describes the approach to take when deciding whether it is economic to sell grain immediately after harvest or to rent or buy grain storage facilities (Rowlands, 1998). The Soil Association has a general leaflet on organic arable crops but as far as storage is concerned it only covers "Standards" issues.

**Organic information abroad**
There appears to be little information on organic grain storage published abroad. The Research Institute for Organic Farming in Switzerland produces a range of booklets in German and French on organic farming; only one deals with cereals and has one paragraph on storage where it recommends storing grain below 14% moisture content and cooling to 15°C or below before entering the store. The Danish Agricultural Advisory Centre has produced a booklet on grain storage which is suitable for both conventional and organic growers (Anon., 1995). The emphasis is on drying and cooling with no mention of post-harvest chemicals. Storage of seed is also covered. The advisory service also provides up-to-date information on its website but there is a fee to use it, and both booklets and the website are primarily in Danish.

Appropriate technology Transfer for Rural Areas (ATTRA) is a government funded advisory body in the USA for sustainable agriculture. ATTRA does not publish booklets specifically on organic grain storage but they do have an information pack which contains a letter outlining useful information available together with photocopies of articles on pest identification, grain monitoring, biological control, and physical control methods including the use of carbon dioxide to fumigate insect-infested grain (Powell, 1992). The Organic Federation of Australia was also contacted but was unable to provide any information on grain storage.

**Decision-support software for organic grain storage**
As a result of the review, it was decided to prepare an organic module for the "Integrated Grain Storage Manager" (IGSM) decision-support software. The IGSM expert system has been developed with funding from HGCA and MAFF for use by those who are responsible for the storage of grain. The software will run on an IBM compatible PC with 640Kb of memory, VGA graphics and Windows 3 or later. It incorporates the latest research information on grain storage problems and provides an encyclopaedia of grain storage advice. It also encourages the user to record sampling results which can subsequently be used in quality assurance statements consistent with the Assured Combinable Crops Scheme. In addition, automatic checks are done on any monitoring data and the user is notified of potential problems. The system can also be used to seek advice on a particular problem by using the problem solving section.

The analysis of pest management strategies for organic grain storage carried out in fulfilment of Objective 3 in the current review has been used in the preparation of the organic module. The new module is a modified version of the 'conventional' system with all the references to chemical pesticides being removed except for one fabric treatment. Much of the basic advice and modelling are unchanged because IGSM was designed to provide the 'least cost' method for the safe storage of grain which is, in most cases, the prevention of infestation by good hygiene and careful use of drying and cooling. This advice is just as valid for 'organic' as for ‘conventional’ storage. The main difference in the organic version is that the chemical controls for existing infestations are not available to the user and therefore the need for correct storage conditions are emphasised more strongly. The problem solving elements of the program still exist but the options are rather more limited. The record keeping and monitoring sections of the program are available to the user to record information about the store, the parcel of grain and what has been done to it whilst in storage. The tools for

calculating moisture content from relative humidity and changes in weight due to drying are also included. The encyclopaedic section of the program has been heavily revised to exclude the information on chemicals but more importantly to include more information on cleaning of grain stores, alternatives for pest control such as the use of biocontrol, cleaning and heat, organic pesticide treatments for the store fabric, and information on the market requirements. The existing ‘pest library’ has been improved with clearer images of the pests. The program, along with an electronic manual in Adobe Acrobat format, can be distributed on floppy discs or on a single CD-ROM.

As a result of this review, a booklet on "The organic storage of grain" is also being prepared in collaboration with the Soil Association. This will join the series "Soil Association Technical Guides for Organic Crop and Livestock Production" .

## Objective 3. Identify areas of current storage technology requiring a minimum of modification for a smooth transfer from the conventional to the organic sector.

Objective 3 has been met in full. The review considered areas of commonality and conflict between conventional and organic approaches to grain storage, and the alternatives to the use of pesticides and fumigants that are currently available or that will require only a minimum of modification to attain organic approval. In particular the need for organic alternatives in four areas were identified:

- Grain store structure treatments.
- Admixture chemicals for prophylaxis and control of infestation in grain.
- Top dressing of cooled bins as part of an integrated pest management strategy.
- Fumigation for prophylaxis and treatment of infestation.
- Vertebrate pest control.

**Grain store structure treatments**

In the UK, the most important grain beetle pests rarely fly and do not infest grain in the field. They are most commonly spread between stores on loads of grain, animal feed, contaminated lorries or equipment. Once infestation has reached a store, it can remain in the structure of the building for many months or even years, until conditions allow it to move into a bulk of grain and develop to a noticeable level. Therefore, insects in the structure of a store are a key factor in whether or not grain becomes infested during storage. The treatment of an empty grain store before it is re-filled with grain can help to prevent infestation by reducing the number of pests or by eliminating populations. The technique is relatively easy to use as treatments can be done by farmers or storekeepers if they are properly trained. All grain stores, even relatively modern structures, provide harbourages for pests. These include cracks and crevices, dead spaces behind equipment, the inside of conveyers, aeration ducting, etc. If the store is old or in bad repair, the potential for harbouring insects is far greater. In general, most of the pests avoid light and will remain hidden in the harbourages. As a last resort, hidden infestation can be tackled by treating the store structure with an approved contact pesticide. In commercial stores with a regular throughput of grain, the disinfestation process should be carried out every time a section of the store is emptied. In farm grain stores, annual disinfestation is required.

<u>Cleaning the store</u>

Accumulations of dust, spilt grain and empty bags, create an environment which favours insects and also protects them from contact with any approved pesticide that may be necessary. Therefore, cleaning is essential for the disinfestation of an empty store. All dirt and debris must be removed and an industrial vacuum cleaner will make this task easier. Immediately after cleaning, all the debris must be removed from the store and vacuum cleaner for disposal, preferably by burning. The cleaned store should then be inspected for structural defects and water leaks, as it is much easier to rectify any faults at this stage.

<u>Vacuuming</u>

By removing the grain and dust residues, a food source for the pests while the store is empty between harvests is also eliminated. The counter-argument to this is that it may also remove the predators and parasites which limit pest numbers. Nevertheless the overall conclusion must be that this is good practice, and it is widely carried out although access to roof and dead spaces often proves inhibiting. However, the effectiveness of the method has never been examined experimentally.

<u>Steam-cleaning and pressure washing</u>

Steam cleaning and high pressure cleaning with water and hypochlorite solution followed by rinsing with potable water are permitted methods of store cleaning. This service may be offered by certain contract companies and is featured sporadically in the farming press but there is no information on temperatures achieved, penetration into dead spaces or mortality of pests produced. This would be best carried out following a thorough cleaning of residues by vacuuming, etc. However, no experimental evidence exists to show that either method reduces insect populations.

<u>Biocontrol for store structure treatments</u>

The use of biological control has been opposed by some sections of the UK market because of the risk of contaminating the product with the control agent, which may be regarded as being as bad as contamination by the pest (Cox and Wilkin, 1996). However, this should not preclude the use of low levels of biological control agents beneath the detection threshold, applied intelligently to control low levels of pests, particularly in inaccessible dead spaces and storage warehouses, if not directly to food itself (Cox, 1999). Cleaning of organic grain before it is marketed is recommended to avoid problems with rejection due to contamination with beneficials.

*Predators and parasites*. Registration is not required for predatory or parasitic insects and mites that already occur in the UK. Predators include the mite *Cheyletus eruditus* Schrank which preys on pest mites and the eggs and young larvae of most storage pests. It has been applied as a treatment to empty grain stores in Europe (Zdarkova and Horak, 1990). Approximate costs are £2 per 100m². It is unlikely to be effective within stores where the grain temperature is below 18ºC as it requires temperatures above 20ºC for good activity (Zdarkova and Fejt, 1999). There are a number of parasitic insects which can be effective against moth and beetle pests but they are often specific to particular pest species and may have to be applied as a mixture of species (Cox and Wilkin, 1998). Preventive grain storage management strategies that seek to enhance naturally occurring populations of predators and parasites may be more in keeping with the philosophy of some organic farmers than inundative releases during which overwhelming numbers of mass-produced individuals are released to achieve rapid pest control. Further work is needed to assess the potential of predators and parasites as control agents in UK flour mills and grain stores.

*Pest pathogens*. *Bacillus thuringiensis* is one of the best known insect-specific micro-organisms that is used to control some insect pests. 'Dipel', produced by Abbot Chemicals, is registered in the USA where it is applied as a wettable powder to the surface layer of grain in a store. At present, there are no products registered for use in stored grain in the UK. A study, jointly funded by MAFF, HGCA and DETR, is in progress at CSL and CABI Bioscience to identify the most effective naturally occurring, insect-specific fungi associated with storage pests in Britain. It will evaluate their use for the control of stored food pests in the building fabric of grain stores and flour mills, either alone or as part of an integrated pest management strategy.

<u>Contact pesticides</u>
Pesticides should only be used as a last resort in an organic system. According to UKROFS and Soil Association standards, the only permitted contact pesticides approved for use in organic grain stores are pyrethrum/pyrethrins extracted from *Chrysanthemum cinerariifolium*. These should only be used if store cleaning is unsuccessful and monitoring indicates that pests are still present. It must only be applied to the store structure; all grain and other food products must be removed from the store before application, and treated surfaces should not come into contact with grain. Under no circumstances is the pesticide to be applied to the grain which is strictly prohibited under both organic standards and the UK pesticide regulations.

**Admixture chemicals for prophylaxis and control of infestation.**
Three compounds are currently cleared for use for application to conventional grain. These chemicals may be applied to uninfested grain as it enters the store as an insurance against pest ingress. However, in the UK prophylactic admixture can be largely replaced by efficient ventilation of the grain. If the moisture content of the stored grain is kept to about 14.5% (in equilibrium with a relative humidity below 65%), to prevent mite and mould increase, then cooling the grain to below 15°C within a fortnight and to below 10°C within 144 days, will prevent the commonest grain pests, the saw-toothed grain beetle, *Oryzaephilus surinamensis*, and the grain weevil, *Sitophilus granarius,* from completing their life-cycles (Armitage *et al*., 1991). In practice, this is always possible in the UK from July onwards and by the end of December, temperatures near 0°C should be achieved. However, efficient operation of aeration systems depends on monitoring and recording of grain temperatures; it is greatly enhanced by automatic fan control, especially the use of thermostats that work on the temperature differential between air and grain (Armitage and Llewellin, 1987).

Conventional cooling systems depend on under-grain or under-floor, horizontal duct systems which often need to be built into the store. As assurance schemes demand that better attempts are made to maintain grain quality, the cheaper, flexible "Pedestal" system has become popular. Pedestal systems are vertically installed and have the advantages that they are cheaper to install into existing stores and that there is less chance of damage to ducts by driving tractors over them. However, their operation is not well-researched and depends on correct duct spacing, duct perforated area and diameter and selection of optimum fan power, just as do conventional systems. Unscientific and unsubstantiated claims have been made by at least one manufacturer about their ability to dry grain. It is clear that substantial research is required to ensure their optimum operation.

Admixture chemicals may also be applied to grain against infestations that are detected during storage, and here non-chemical alternatives are not so readily applicable. A conventional alternative to admixture in this context, would be fumigation by methyl bromide or phosphine but neither are appropriate for organic storage. In any case, the use of methyl bromide is being phased out throughout the EU, in response to the Montreal Protocol to reduce further damage to the ozone layer. Gas-based alternatives that may be permitted in organic systems, such as the use of low oxygen or high carbon dioxide atmospheres, are discussed later.

Low temperature can be used to eliminate infestations but even at the lowest temperatures achievable by aeration in the UK winter (0-5°C) insects will take many months to die (Fields, 1992). Small parcels of grain for specialised use can be disinfested in a day or so at temperatures achievable by a domestic deep-freeze but this is not suitable for bulk grain. In contrast, high temperatures can achieve more rapid disinfestation, and temperatures above 50°C will usually kill insects within an hour or two. In Australia, this theory was tested by the building of specialist heat-disinfestation plants (Evans, et al, 1984) but on most UK farms a hot air grain dryer could achieve the same results. Practical experiments have not been carried out but temperature-time combinations required to kill the most heat-resistant stages of Australian pests have been reported in the literature. This technique has the disadvantage of being relatively expensive, and it means that the grain must be cooled rapidly immediately afterwards to minimise the risk of re-infestation. As with fumigation and unlike chemical admixture, there is no residual protection from re-infestation. Other high temperature disinfestation techniques include microwaves or infra-red emitters, which have been reviewed by Nelson (1975) and Kirkpatrick (1975). However, these novel methods incur substantial capital and running costs and are poorly researched in the grain storage context.

Another piece of conventional equipment that may be used for disinfestation is the grain cleaner. Free-living adult insects may be sieved or aspirated from the grain, although developing stages within the grain are unlikely to be affected (Armitage, 1994; Armitage *et al*., 1996). Nevertheless, combined with other methods such as heating, this technique may offer more than just a cosmetic treatment. As commercial cleaning companies often offer a ‘disinfestation’ service, it seems important to expand the content of this section in the current IGSM.

Percussion is another way that insect mortality may be achieved. While it may not be justified to develop

specialised equipment to achieve insect mortality this way, the process occurs during everyday conveying of the grain. Although various claims have been made for insect deaths occurring during conveying (Banks, 1984), the reality is that only pneumatic conveying achieves substantial mortality, including that of developing stages (Armitage et al., 1995; Bahr, 1991). Again, combined with cleaning, this may offer a non-chemical means of tackling existing infestations in organic grain.

**Top-dressing of cooled bins as part of an IPM strategy**
Cooling grain in-bin or on-floor leaves the surface as the area most vulnerable to infestation. It fluctuates in temperature with ambient, which allows insects to survive the winter there, and it absorbs moisture from the atmosphere which permits mite infestations to develop, despite the low temperatures and moistures beneath. A proven solution to this for conventional grain in the UK was the application of a surface pesticide, raked into the top 0.3m or applied to the last of the grain as it enters the store (Armitage et al., 1994).

A way of preventing the uptake of moisture, investigated with HGCA funding, is to apply fumigation sheeting to the grain surface to prevent moisture uptake in the first place (Armitage and Cook, 1999). This has the added advantage of inhibiting pest ingress by this route. However, the grain would have to be cooled first or the sheeting would have to be of a material, such as Gore-Tex, that allowed air movement but not moisture ingress. Use of a de-humidifier together with surface sheeting may provide a greater guarantee against moisture uptake but capital and running costs might exceed the quantifiable benefits.

**Fumigation as prophylaxis and treatment of infestation**

Currently fumigation with phosphine is recommended for prophylaxis where a store has been infested the previous year or as a cure of an existing infestation. Methyl bromide is mainly used to fumigate infested imported commodities on boats. These techniques are intended to disinfest grain quickly, preferably over a weekend and certainly within a week. They are also applied to empty structures such as mills and warehouses. Clearly, these approaches are not appropriate for organic grain.

Controlled or modified atmosphere treatments would appear to be direct alternatives to fumigation with poisonous gases. They depend on replacing the atmosphere between the grains by one high in carbon dioxide ($CO^2$) or low in oxygen ($O^2$) (Bell and Armitage, 1992). As with conventional fumigants, they depend on the gas-tightness of the grain container, and most unsealed bins or stores will require lining of bulk-heads, etc. with polythene, and sealing of aeration ducts, auger tubes, etc. $CO^2$ atmospheres need to be generated from cylinders or other bulk supplies but low $O^2$ , that is high nitrogen ($N^2$), atmospheres can be generated in a number of ways. The most economic is by combustion of propane but $O^2$ can also be removed by molecular sieves. For effective control, $CO^2$ atmospheres need to achieve about 60% $CO^2$ in air, while low $O^2$ atmospheres may comprise 87-89% $N^2$ and 10-12% $CO^2$. Continuous flow avoids the need for absolutely air-tight structures. The time-scale for such treatments is about 2-3 weeks at 25 °C and trebles at 15°C, so the comparison with fumigation as a means of rapid disinfestation is not entirely justified. Although exposure times can be reduced by increased temperature or decreased pressure, neither of these augmented approaches appear economical or practical for grain storage. However, in the USA food grade $CO^2$ has been used to treat organic grain at 21-24°C that was badly infested with the rust-red grain beetle, *Cryptolestes ferrugineus* (Powell, 1992). It was claimed that dis-infestation was achieved by pumping the gas into the grain to maintain a concentration of 40% for 72 hours, so this method may be worth further consideration for organic grain in the UK.

Hermetic storage depends on the same principle but is a passive process and thus depends on better airtightness (Bell and Armitage, 1992). Damp grain above 17% m.c. will use up the $O^2$ in a sealed silo as the fungi respire and the $CO^2$ will rise to 30-50%, with $O^2$ atmospheres of 1-2%. As the grain dies during this process, the result is only suitable for animal feed and could be regarded as an alternative to drying. Grain infested with insects will also use up the oxygen if held in a sealed container and, having done so, will themselves die. However the speed of this process depends on the infestation, and in reducing the $O^2$ the pests will also be damaging the commodity. It is possible that this process could be enhanced by adding a small proportion of damp grain, thus calling upon the fungi to enhance the speed of $O^2$ removal.

**Vertebrate control**

Birds

To prevent birds entering stores and contaminating the grain, the following actions should be taken. Discourage nearby roosting. Anti-roost devices, such as suspended wires, may work against pigeons but not against sparrows or starlings. Block gutter level entry and pay special attention to broken windows, door tops, etc. Use netting for exclusion; a 19 mm mesh should exclude the smallest avian pest - the sparrow. Distress calls may deter some species including starlings.

Rodents

To minimise the problem of rodents, the following strategies should be adopted. To control rodents with minimal use of pesticides, the aim should be to maintain high standards of hygiene and proofing inside and outside storage facilities. Denying rats and mice access to food and shelter should prevent infestations developing in the first place. Rats can squeeze through holes down to around 14mm in diameter and mice 8mm in diameter. Keep store and surrounds clean and in good repair. Edible and inedible spillage should be swept up daily and removed. Clear undergrowth, bushes, etc. from directly around store as these provide cover. Repair doors, windows, wall sheeting, edges of concrete aprons, plinths, down pipes, etc. Fit internal gauze baffles and external guards to down pipes. Harbourage such as pallets, packing cases and discarded machinery should be removed. Early detection will minimise the cost of control. Monitor for rats using un-poisoned grain or attractive food. Mice can be detected using non-poisoned wax blocks. Once the population size is estimated then develop a control strategy.

Poisoning with approved products is currently the most efficient control method, but easy access by rodents to alternative food and the presence of resistance to anticoagulant rodenticides can severely reduce treatment success. Under UKROFS and Soil Association organic standards the same roticides permitted for control in conventional farming are permitted in organic systems, provided that the stored product can not be contaminated or the poisons eaten by other animals or wildlife. The only difference is that 'static bait traps' must be used. For mice it may be necessary to keep permanent static poison bait traps. For rats often an external barrier of bait points can be appropriate before they breach the proofing of the store.

Trapping can be successful, but is labour-intensive and may only be cost-effective against small numbers of rats and mice. Traps can be effective for small populations but need to be used at high densities. Place rat traps under bricks or pallets in such a way that non-target animals can not gain access. Repellents, whether chemical, ultrasonic or electromagnetic are not yet reliably effective. Ultrasonic devices are not considered effective and cats can leave their own contamination!

## Objective 4. Identify areas where appropriate organic alternatives to conventional storage procedures do not exist that will require further research and development to find replacements.

Objective 4 has been met in full. The following areas have been identified as requiring further research and development that are likely to provide opportunities for improving the storage of organic grain:

**1. Store structure cleaning.**
Assess the effectiveness of organically acceptable methods of grain store structure cleaning, including :
a) The effectiveness of vacuum cleaning and steam treatments. Vacuum cleaning is widely used and steam treatments are available commercially. However, in practice these treatments tend to be applied when operationally convenient rather than when actually needed. The effects of these treatments on both pest and beneficial arthropod populations have yet to be examined experimentally.
b) The feasibility of using diatomaceous earths. Diatomaceous earths (DEs) are the fossilised remains of plants, based on silicon dioxide. These may be of marine or freshwater origin, the latter being preferred on health grounds because of their lower crystalline content. They have a physical mode of action by absorbing the waxy elements of the arthropod cuticle, disrupting the waterproofing and causing them to die by desiccation (Arthur, 2001; Mewis and Ulrichs, 2001). Most commercially available DEs are enhanced with silica aerogels, produced by drying aqueous solutions of sodium silicate. In the UK, preliminary tests have indicated that applications of dry dust at 1-3g/kg of grain may be necessary to inhibit population increase of most insects and mites (Cook *et al.,* 1999; Cook and Armitage, 1999). DEs can also be applied as a slurry which has the advantage of minimising dust nuisance but reduces efficacy. In Australia, fabric treatments are applied at rates of 6g/m$^2$ as a 10% aqueous slurry. At the moment, DEs are not registered for application to grain store surfaces or to grain in the UK but are used in other countries including the USA, Canada, Germany and Australia, and their registration in the UK may be imminent.

**2. Grain drying and cooling systems.**
a) Develop more energy efficient drying and cooling systems for grain. For example, the further uptake and development of alternatives to underfloor ducts for cooling could be considered. 'Hot-spot' coolers are portable aeration systems comprising two metres of duct with a threaded tip which allows the duct to be screwed into the grain bulk by using an attached handle. Fans of about 0.1kW then suck air from the grain surface toward the duct, and insects following the cooling front are often voided through the fan. These coolers will usually cool about 4 tonnes of grain per day, based on observations in 40 tonne bins. A relatively new development in aeration design has been the vertical aeration system, sometimes described as "Pedestals". Typically these comprise a one metre upright perforated section of duct connected by extendible necks to a centrifugal fan which usually exhausts the air ; so the system is often based on suction although conversion to blowing is easily arranged. These vertical aeration systems are basically permanent installations of aeration spears or 'hot-spot' coolers but they are able to ventilate larger volumes and greater depths of the stored grain. One manufacturer recommends pedestals of 10-20 cm diameter for cooling 40-500 tonnes of grain, each using 0.3-4.5 kW giving 575-2870 m$^3$/h and maximum grain depths of 2-10 metres. The recommended distance between pedestals varies with moisture content and ranges from 3.0-4.5 metres for 10 cm ducts and 575 m$^3$/h to 7.5-

10.0 metres for 20 cm ducts and 2870 $m^3$/h. The capital costs of such installations when used to cool grain are around £2 per tonne. These relatively low costs together with the reduced chance of damaging vertical above-floor ducts when compared to horizontal ducts have contributed to their increasing uptake in the UK.
b) Consider the use of renewable energy sources such as wind, water and solar power or the processing of waste products and energy crops. A simple way of using solar energy, for example, is to paint the roof of an outside bin black and draw air downwards through the grain from the top. The main advantage of using solar heated rather than ambient air is that the final moisture content of the grain will be lower, thereby enhancing grain quality and increasing the safe storage period.

**3. Invertebrate pest monitoring and sampling strategies.**
a) Traps currently on the market in the UK for use in grain stores to provide early warning of infestation are a marked improvement on earlier methods using spear sampling etc.; even so, less than 3% of grain beetles and 1% of grain weevils present in a grain bulk were caught in traps over an 8 week period (Cogan and Wakefield, 1994). The addition of an attractive lure to a trap gave a six fold increase in the catch of the grain weevil, *Sitophilus granarius,* compared to traps without lures (Wakefield, 1997). Further work with semiochemicals and food lures should lead to greater improvements in the current methods for monitoring invertebrate pests (Cox and Collins, 2001). In the longer term, further development of systems using machine vision and electronic noses may lead to practical applications for improved grain pest monitoring (Ridgway, 1997; Ridgway and Chambers, 1998).
b) Additional work is also required to identify better trapping and sampling strategies for invertebrate pest monitoring, together with more accurate interpretation of trap catch data and correlation with pest population density (Subramanyam, Hagstrum and Schenk, 1993; Wakefield and Cogan, 1999).

**4. Hot air disinfestation.**
Investigate the practicality of using grain dryers for disinfestation by hot air. Stored grain arthropod pests usually die in less than a day at 40°C, an hour above 50°C, and a minute above 60°C (Fields, 1992). Thus, high temperature disinfestation may be a valid alternative to pesticide treatment of stored grain. In Australia, experimental fluidised beds have been designed for this purpose but the same effect should be achievable using hot-air dryers. Practical field-scale experiments are needed to determine the optimum temperatures to use in terms of costs and success in killing developing pests within grain without damaging grain quality. Clearly the maximum temperature that can be used for seed grain will be much lower than that for feed grain.

**5. Biological control for grain structure treatments.**
Work in the following areas should be undertaken:
a) Conduct a comprehensive survey of organic grain storage facilities to determine the range of pest and beneficial arthropod species present and their population densities.
b) Study the effectiveness of using biological control agents to remove residual infestations hidden in grain store structures.
c) Consider strategies that might be used to encourage the development and conservation of existing natural populations of beneficial invertebrates.
d) Produce clear, easy-to-use identification guides to help in distinguishing between pest and beneficial insects and mites.

**6. Biological control for surface infestation of grain.**
Additional studies should be considered to:
a) Assess the practicality of using top-dressing or bait trap application techniques for biological agents to control grain surface infestations of insects and mites in cooled bins.
b) Devise methods for the effective removal of beneficial invertebrates from grain before marketing. For example, the use of cleaner-augers, reciprocating and aspirated sieves has been shown to remove many insects and mites (Armitage, 1994; Armitage *et al.,* 1996).

**7. Semiochemicals for beneficials.**
Work should be conducted to test the concept of using semiochemicals to improve the effectiveness of parasitoids and predators. The use of semiochemicals to manipulate the behaviour of predators and parasitoids has been demonstrated for the improved control of insect pests of growing crops, including aphids

in UK winter wheat (Kirkland *et al.,* 1998; Agelopoulos *et al.,* 1999). Similar techniques could be used to attract beneficials and encourage them to remain within specific target areas in grain stores, thereby improving efficacy and reducing the risk of contamination (Schoeller and Prozell, 1996).

## Main implications of the findings

Organic farmers are seeking to work with natural systems rather than to dominate them; thus, the emphasis is on preventive grain storage management rather than preventive grain treatments. The main problems associated with the storage of organic grain, namely the prevention of attacks by pests and diseases, appear to be similar to those experienced by conventional growers but with the additional constraints of avoiding the use of pesticides by managing the storage environment to minimize the build-up of pest and disease problems.

Few of the farmers contacted made use of pest detection aids such as traps or conducted regular monitoring of grain for pests, and accurate measurement of the grain temperature and moisture content occurred only rarely. The condition of the grain while in store tended to be checked infrequently and on a visual, ad hoc basis. Since organic storage depends on physical pest control methods which rely on careful monitoring for their success, this is unacceptable, even for short term storage of a few months, because of the potential for rapid increase in pest numbers under favourable conditions. Also, it could lead to problems when grain is stored for longer periods and in grain required for seed, malting or sprouting where even slight deterioration can lead to unacceptably poor germination as well as contamination from moulds, mites and insects.

An Organic Module for the "Integrated Grain Storage Manager" software package has now been produced. This and the Soil Association Technical Guide on the organic storage of grain should satisfy the need identified by this project for an up-to-date information source, specifically aimed at providing farmers with advice on all aspects of organic grain storage.

## Possible future work

A number of areas have been identified where appropriate organic alternatives to conventional storage procedures do not exist that will require further research and development to find replacements:

- Assess organically acceptable methods of store structure cleaning, including the effectiveness of vacuum cleaning and steam treatments, and the feasibility of using diatomaceous earths.
- Develop more energy efficient systems for drying and cooling grain and consider the use of renewable energy sources.
- Develop improved methods of invertebrate pest detection and monitoring, including enhanced trap design and the incorporation of lures, and more effective sampling strategies.
- Assess the practicality of using grain dryers for stored grain disinfestation.
- Study the effectiveness of using biological control agents to remove residual infestations hidden in grain store structures.
- Conduct a comprehensive survey of organic grain storage facilities to determine the range of pest and beneficial arthropod species present and their population densities.
- Consider strategies that might be used to encourage the development and conservation of existing natural populations of beneficials, and produce easy-to-use identification guides to help in distinguishing between beneficials and other species.
- Assess the practicality of using top-dressing or bait trap application techniques for biological agents to control grain surface infestations of insects and mites in cooled bins.
- Assess the feasibility of covering bulks of stored grain with a breathable material to prevent birds contaminating the grain and to prevent the absorption of moisture at the grain surface.
- Assess methods for the effective removal of beneficial arthropods from grain before marketing, including the use of cleaner-augers, reciprocating and aspirated sieves.
- Consider the use of semiochemicals to improve the effectiveness of beneficial arthropods in grain stores.

## Action resulting from the research

- An organic module for the IGSM decision-support software has been developed.
- A booklet on the organic storage of grain has been produced in the Technical Guides series published by the Soil Association.
- A technical article on the findings of the project, together with practical advice on grain storage, has been written for publication in the 'Organic Farming Journal'.
- Material has been prepared for a Soil Association workshop and an Elm Farm Research Centre Network Event, to be held after the current Foot and Mouth disease outbreak comes to an end.

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