SECOND EDITION

Updated for 2003

HGCA

# the grain storage guide

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**Summer 2003**

HGCA

**Dear member**

First published in 1999, HGCA's *Grain storage guide* was widely accepted by the industry. We printed 45,000 copies and it is now required reading by most assurance schemes. Principles laid down in the original publication remain sound – effective grain storage is crucial to successfully producing and marketing grain. However, legislation, technology and pesticides have all changed, so it is now time for an update.

New legal limits for ochratoxin A contamination in grain now apply. Treatments that can be used on stored grain as part of an integrated strategy have changed. However, check what treatments your buyer will accept. Warmer winters mean that using ambient air to cool grain takes longer, so moisture content assumes greater importance.

Two companion publications now provide more detail on some aspects of grain storage. These are *The rodent control guide* and *Grain sampling – a farmer's guide*.

Any guide is bound to have a limited 'shelf life'. To avoid confusion, I suggest you throw away your old copy and now use this 'updated' guide.

Yours sincerely

**Professor Graham Jellis**
Director of Research
HGCA

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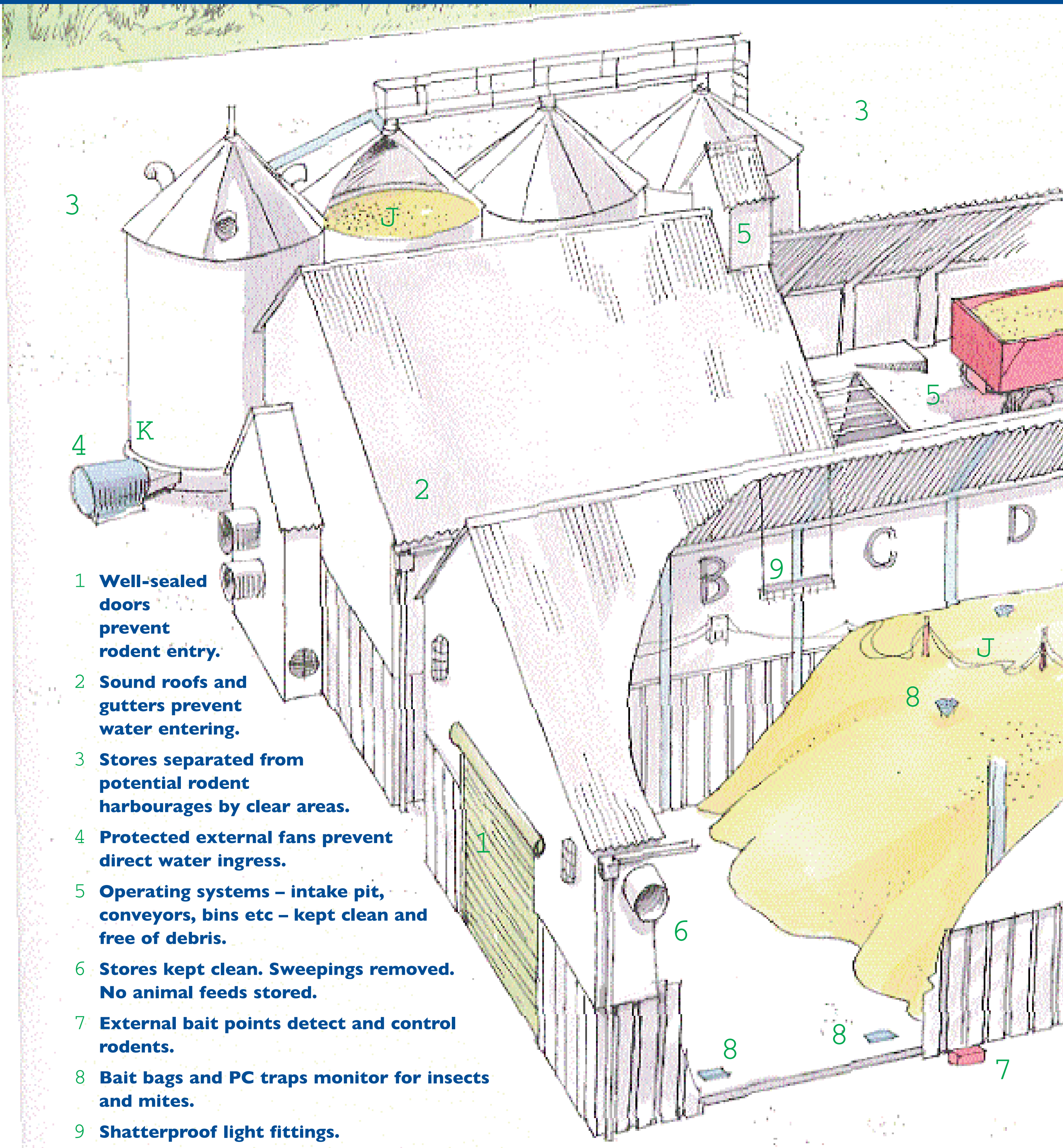
This guide is endorsed by the following organisations:

ASSURED COMBINABLE CROPS Producing Trust · FABBL ASSURANCE · British Malt (Maltsters' Association of Great Britain, Founded 1827) · nabim · SCOPA Seed Crushers' and Oil Processors' Association · Scottish Quality Cereals · UKASTA A Force in Food and Farming · TASCC

# FEATURES OF GOOD STORAGE




1 **Well-sealed doors prevent rodent entry.**

2 **Sound roofs and gutters prevent water entering.**

3 **Stores separated from potential rodent harbourages by clear areas.**

4 **Protected external fans prevent direct water ingress.**

5 **Operating systems – intake pit, conveyors, bins etc – kept clean and free of debris.**

6 **Stores kept clean. Sweepings removed. No animal feeds stored.**

7 **External bait points detect and control rodents.**

8 **Bait bags and PC traps monitor for insects and mites.**

9 **Shatterproof light fittings.**

J **Adequate space above grain for air circulation.**

## THREE STEPS TO SUCCESSFUL STORAGE

- **Dry**
- **Cool**
- **Monitor**

# 1 PREPARATION

## BACKGROUND

Grain store structure, equipment and residues all threaten the quality of harvested grain. Action should be taken well before intake to ensure a contaminant-free environment.

Surveys have shown that 10% of farms and 8% of commercial stores had primary pests *(Section 7)* in empty stores.

Cleaning alone will not eliminate all pests in empty stores, nor will pesticide treatment.

Good hygiene, effective grain drying and cooling and well-targeted pest control all combine to maintain grain quality in store.

Conveying may damage grain and make it more susceptible to insect, mite, fungal and mycotoxin attack. Handling equipment should always be adjusted to avoid such damage, eg augers should be run full.

*Use insect traps in empty stores to assess if residual infestations exist, before using pesticides on the fabric.*

*Use appropriate equipment for each task.*

### Store surface treatments

All parts of the store, including the inside of bins and other surfaces in contact with grain, may be treated with the following chemicals:

**Actellic** – pirimiphos-methyl (spray liquid)

**Reldan 22** – chlorpyrifos-methyl (spray liquid)

The following product may be applied to the store structure, including dead spaces, but NOT to surfaces which come into contact with grain:

**Crackdown Rapide** – deltamethrin and synergised pyrethroids (spray liquid)

Dust formulations of diatomaceous earth (DE), which act by desiccating insects, may be applied to dead spaces and structural surfaces. Check whether this treatment is accepted by your buyer.

*Pesticide registrations change. Check current approval status with Pesticides Safety Directorate (www.pesticides.gov.uk) before use. Follow label instructions on use and allow specified time intervals before storing grain. Record all pesticide use.*

Measure the area to be treated, in square metres. Then, following the label instructions, calculate the amount of concentrate and the amount of diluted spray required. Apply using an appropriate sprayer to ensure even cover. Before treatment, turn off the mains electrical supply if there is any risk of water-based sprays penetrating electrical fittings. Protect, or take care not to treat, electric motors and similar equipment. Two days after treatment, inspect the store and monitor (using insect traps) for live insects. If large numbers are found in a particular area, investigate and, if necessary, re-clean and re-treat.

### Alternative building uses

Ideally use dedicated grain stores. Where buildings are also used for animal feed, machinery or livestock care must be taken to avoid taints or contamination of subsequently stored grain.

**Like any foodstuff, grain must be protected from contamination. Storage facilities and grain condition are both critical. Stores must be clean, dry and well ventilated. Equipment must work**



| ISSUE | ACTION |
|---|---|
| **Equipment must function effectively:**<br>– to ensure grain conditioning on intake<br>– to reduce spillage, damage or loss<br>– for staff safety. | ● Clean, check and service key equipment.<br>● Review electrical and mechanical safety.<br>● Ensure staff are trained appropriately. |
| **Common structure problems:**<br>– water ingress<br>– pest entry<br>– harbouring pests<br>– risk of contamination. | ● Examine roof for leaks and broken gutters.<br>● Look for structural defects in walls or evidence of ground water ingress.<br>● Eliminate dead spaces that trap residues or cause problems with cleaning.<br>● Proof against rodent and bird entry.<br>● Use shatterproof covers on lights. |
| **Dirt and debris:**<br>– shelter pests<br>– contaminate incoming stocks<br>– hinder proper inspection of equipment and structure<br>– prevent pest detection<br>– hinder effective pest control. | ● Use an industrial vacuum cleaner. Remove rubbish (including vacuum cleaner contents) immediately after cleaning.<br>● Burn or dispose of rubbish well away from store.<br>● Consider cleaning grain to cut pest risk.<br>● Make final inspection for waste residues. |
| **Store infestation**<br>The main threat to stored grain is from pests in the store structure.<br>Bought-in grain or feed, lorries or equipment can also introduce storage pests.<br>Current best practice is to use a pesticide only where it is necessary.<br>Risk should be assessed taking into account infestation history, physical controls and intended markets.<br>Poorly-sealed storage areas will cause difficulties if fumigation is necessary *(see Section 11)*. | ● Monitor store for pests with insect traps. If live insects are found, treat structure and protect incoming grain.<br>● Ensure that properly trained staff or contractors apply treatments to clean, empty stores.<br>● Use only pesticides, or mixtures, registered for use in empty grain stores, and approved by customers.<br>● Treat all interior surfaces with pesticide or DE, especially those that might harbour insects, at least three weeks before filling store.<br>● If store has been infested within past two seasons, apply an insecticide to structure.<br>● Store all feedstuffs and similar commodities away from the main store. |
| **Cleaning and disinfection**<br>Buildings used for livestock as well as grain storage must be disinfected to reduce risk of disease transmission before storing grain. | ● Power wash building structure.<br>● Disinfect with appropriate food-safe products.<br>● Leave to dry. |

# 2 MOISTURE

## BACKGROUND

### Relative humidity and moisture content

Relative humidity (rh) is a measure of the air's moisture content. It is expressed as a percentage of the moisture that it could hold, if fully saturated, at a given temperature. The safe moisture content (mc) of grain for storage is related to rh. Mould growth and mite reproduction stop at 65% rh.

### Moisture change at grain surface

The grain surface absorbs moisture in winter. Even when bulk moisture content is low, increases in surface mc can lead to very high mite populations – as the example data shows. Such problems are less likely where initial mc is very low.

| Initial bulk mc | Surface mc in winter | *Lepidoglyphus* mites at surface |
|---|---|---|
| 13.5% | 17.5% | 124/kg |
| 15.0% | 18.6% | 3762/kg |
| 16.5% | 19.4% | 8488/kg |

The risk of moulds is increased by high mc and can lead to mycotoxin production and grain rejection.

Moisture content is less critical for insects. However, lowering grain mc below 14.5% also reduces rate of insect breeding and increases development time.

### Equilibrium relative humidity

Grain exchanges water with surrounding air. In enclosed spaces, this exchange continues until a balance is reached – the equilibrium relative humidity (erh).

Erh decreases with temperature (see below).

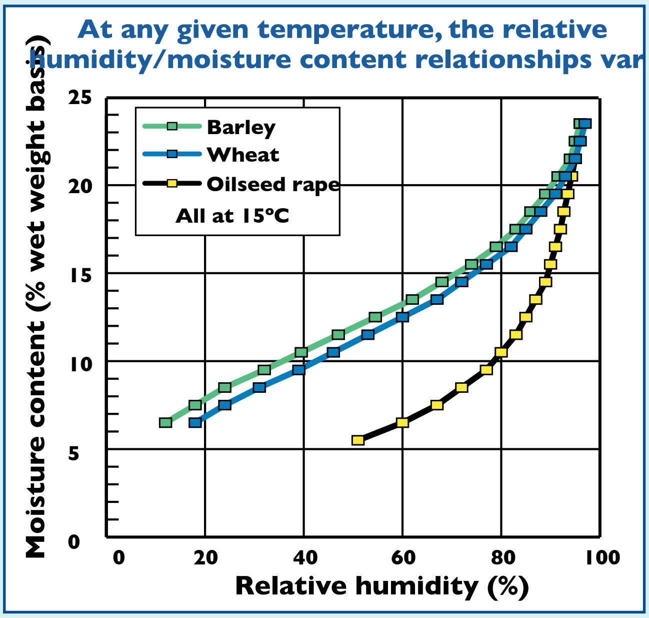
**For a given moisture content cooler grain is safer to store because its erh is lower.**

| Moisture content | Wheat temperature | | |
|---|---|---|---|
| | 5°C | 15°C | 25°C |
| 16.5% mc | 68% erh | 74% erh | 76% erh |
| 15.5% mc | 62% erh | 69% erh | 71% erh |
| 14.5% mc | 56% erh | 64% erh | 66% erh |
| 13.5% mc | 49% erh | 58% erh | 59% erh |

**Key** over 65% erh below 65% erh

For example, the above table shows that at 5°C, wheat at 14.5% mc has an erh of 56%. The same grain stored at 25°C at the same mc has an erh of 66%.

For barley or oilseed rape the relationship would be different (see graph below).




### Moisture measurement

Measurements can be direct or indirect. In the standard direct method (ISO/BSI 'Oven method') a known weight of ground grain is dried at 130°C until dry matter weight remains constant. Duplicate samples must be within 0.15%. Grinding and temperature control are both critical.

Moisture meters measure mc indirectly using either grain resistance or capacitance. They are less accurate (±0.1% at best, usually ±0.5%, sometimes ±1.0%) and annual calibration is essential.

**Moisture management is vital to prevent spoilage in stored grain. Temperature and moisture interact to provide suitable conditions for fungi**



| ISSUE | ACTION |
| --- | --- |
| **Moisture content targets**<br>Grain is at risk of spoilage until dried to 14.5% mc for cereals and 7.5% mc for oilseeds. | • Ensure your system has adequate performance.<br>• Monitor progress of drying until required mc is achieved. |
| **Moisture content change**<br>Grain moisture content is linked to the relative humidity of surrounding air and may change over time. | • After drying, take samples from the bulk each week until grain temperature stabilises.<br>• Take as many samples as possible and determine mc without delay. Keep samples in a water-tight container with minimum free air space and at even air temperature.<br>• Mix each sample thoroughly before checking mc using a reliable meter. |
| **Calibration**<br>Poor meter calibration is a common cause of grain rejection. Species and variety affect both capacitance and resistance. | • Calibrate moisture meters against oven standards **each year** to ensure accuracy.<br>• Replace, or recharge, batteries regularly. |
| **Moisture, mites and moulds**<br>After drying, mc of surface layers can rise or fall due to ambient conditions. This is difficult to control. Surface mc may rise to 18% or more, encouraging mites – generally from October onwards as grain absorbs atmospheric moisture. | • If surface mc rises by 2% or more in a week check for condensation, leaks, hot spots or insects.<br>• If mc (at 1 m or more deep) changes significantly, identify cause – unless a bulk drying system is being used. |
| **Moisture and markets**<br>Many sectors of the cereal grain market accept that it is good practice to store grain at 14.5% mc. However, specific markets have specific needs, eg millers require wheat to be safe and fit for purpose, although most accept wheat at up to 15%; maltsters require 13% mc to preserve a minimum germination standard of 98%. | • Always dry grain to at least 14.5% mc for long-term stable storage.<br>• Dry and cool high mc grain (above 18% mc) **immediately** to prevent mould growth, mycotoxin formation and taint.<br>• Check mc requirements of specific customers. |

### Change in grain weight on drying (or on re-wetting)

$$X = \frac{W_1(M_1 - M_2)}{(100 - M_2)}$$

$X$ = weight loss
$W_1$ = original weight
$W_2$ = final weight
$M_1$ = original mc
$M_2$ = final mc

**Example:** 100 tonnes of grain dried from 20% mc to 15% mc.

$$X = \frac{100(20 - 15)}{(100 - 15)} = 5.88 \text{ tonnes}$$

Therefore, weight loss ($X$) is 5.88 tonnes and final weight of crop ($W_2$) is 94.12 tonnes.

# 3 DRYING
## – heated-air

## BACKGROUND

There are two basic methods of drying grain – heated-air and bulk drying:

**Characteristics of the drying options**

| Factor | Heated-air drying | Bulk drying |
|---|---|---|
| Capital costs | High | Low – the dryer is the grain store. |
| Operating costs to remove 5% mc | £1.50–2.80/t | £1.65–3.65/t |
| *Grain is dried from 20% to 15% (wet basis) in normal weather conditions using diesel @ 17.5 pence/L (delivered energy value 3.6 MJ/kWh). For further details, see K A McLean (1989).* | | |
| Speed of drying | Fast – hours, as grain layers are shallow and temperatures high. | Slow – days or weeks, as drying front moves through bulk. |
| Management skills required | Lower – follow manufacturer's instructions. | Higher – need to respond to mc and weather conditions. |
| Effects of weather | None | Wet weather slows drying. |
| Effects of initial moisture content | No real problem – may need to dry grain for longer or in two passes. | Drying capacity reduces if initial mc is high. |
| Risks of spoilage | Low or zero risk of slow drying.<br>Risk of over-heated grain.<br>Some risk of over-drying. | Higher risk of slow drying.<br>Low risk of over-heated grain.<br>Some risk of over-drying.<br>Increasing risk of ochratoxin A production above 18% mc.<br>Fungi and mites inevitably increase ahead of the drying front. |

## Heated-air drying

Using air heated to 40°C or higher means that drying is independent of the weather. Grain is in a shallow layer with high airflow so drying is fast. Except in the simplest designs, grain is moved during drying to give more uniform exposure to the air so that over-drying and heat damage are limited. Dryers have to dry to a target moisture, cool the grain and discharge. Heat, generated from oil or gas, should be applied indirectly wherever possible.

There are two drying options:

– **Batch**, where the dryer is emptied between batches. This type is often mobile. Moisture removal depends on the drying time, which can be altered to reach a moisture safe for storage. Cooling time can be set independently of drying time. Some batch dryers mix and re-circulate grain while running to give more uniform drying.

– **Continuous**, where grain is dried without re-circulation. Plant is usually static. The moisture removed depends on the drying time, ie time to pass through the heated air section, which is determined by the grain discharge rate. This also determines cooling time so extra cooling may be needed if grain discharge rate is high.

It is important to avoid hydrocarbon contamination when using oil-fired energy sources. Check burners and set air:fuel ratios to manufacturer's recommendations to ensure efficient combustion. Provide adequate ventilation to prevent fumes being re-circulated into grain. Ensure that burners are serviced and adjusted as recommended by the manufacturer.

Grain that is above 18% mc must be dried **immediately**. Grain below 18% mc should be cooled, to prevent the crop heating up, if harvest backlogs delay drying.

## Bulk or near-ambient drying

*See Section 4*

**Grain stored for more than a few weeks must have a moisture content of 14.5% or less to protect quality and meet contract specifications.**



| ISSUE | ACTION |
|---|---|
| **Drying temperatures**<br>Higher drying temperatures give higher throughput but excess heat can damage quality, especially protein functionality and germination.<br>The general guideline is a maximum of 65ºC at 20% mc, reducing by 1ºC for every 1% increase in initial moisture content. For feed grain, a maximum of 120ºC for 1 hour or 100ºC for 3 hours can be used. Maltsters and millers require that grain temperatures should not exceed 50ºC.<br>Dryer manufacturer's performance tables provide a guide to drying air temperatures that will not damage grain. | ● Set drying temperature carefully. Use manufacturer's guidance to meet market quality requirements.<br>● Consider reducing drying temperature to reduce damage if input mc rises.<br>● Take particular care when drying malting barley to the industry standard of 13% mc. Grain temperature and the time it spends in the dryer (residence time) are both critical. |
| **Controlling moisture content**<br>Over-drying wastes fuel, reduces dryer throughput and may increase heat damage. Under-drying makes spoilage more likely. On a continuous dryer, manual control is difficult because there is a time lag between grain flow adjustment and full effect. Automatic controls, available for most dryers, measure either grain mc at output or temperature of exhaust air off the bed. The latter is only effective when removing at least 4% mc at a pass. | ● Use a drying time that gives the correct moisture reduction.<br>● Use automatic controls where fitted.<br>● If controlling manually, adjust grain flow gradually.<br>● Consider mixing grain before drying to achieve uniform mc.<br>● Dry high moisture content grain (at or above 18% mc) **immediately** to avoid risk of mycotoxin formation. |
| **Safety**<br>Light material can build up inside the dryer and become a fire hazard.<br><br>Exposure to dust from grain, as well as noise from dryers, may be hazardous to health. | ● Pre-clean the grain before drying and clean out the dryer as specified by the manufacturer to minimise fire risk.<br>● Comply with COSHH requirements. |
| **Cooling after drying**<br>Grain must be cooled after drying to stop insects breeding. Cooling in a continuous dryer, with high flow rates, may be insufficient. Cooling time may be set independently of drying time in batch dryers. | ● Measure temperature of grain entering store and cool if necessary. Set cooling time for batch dryers to ensure grain approaches ambient temperature. Further cooling will be needed *(see Section 6)*. |

# 4 DRYING
## – bulk or near-ambi-

## BACKGROUND

Bulk grain, in bin or on-floor, 1.5–4 m deep can be dried by blowing air – only 5ºC warmer than the grain – through it. Drying typically takes at least 10 days with minimum airflows of 180 $m^3$/hour/tonne (100 $ft^3$/min/tonne).

The challenge is to complete drying before fungi and mites exceed acceptable levels. Drying occurs in a layer (the drying zone) that develops at the air inlet and then moves through the bulk. Grain ahead of the drying zone remains wet and may be warm, producing ideal spoilage conditions. Drying zone progress is proportional to air speed.

Grain ahead of the drying zone is cooled by ventilation. This may cause some moisture to condense on surface grain, especially with cool, moist night air above the bulk. However, even when weather conditions do not appear to suit drying, this cooling has a strong benefit as it retards mite and fungal development.

Running costs for drying by 5%, from 20% to 15%, range from around £1 up to £5 a dried tonne. Poor drying can incur costs of up to £50 a tonne, including spoilt grain, and still be unsuccessful.

Different seeds present different resistances to airflow. Therefore, bed depth must be adjusted according to the airflow resistance of the crop (see figure opposite).

### Airflow resistance

A fan overcomes the resistance of the empty dryer plus that of the grain bed to blow enough air through the grain to dry it. If the resistance is too high, the fan pumps insufficient air. Pressure in the air ducts indicates fan performance. Fan manufacturers supply 'fan curves' giving data on air delivery over a range of duct pressures.

### Additional approaches

**Dehumidifiers** remove moisture from air and add heat, to reduce rh to a pre-set value. They even allow drying in wet weather and use electricity efficiently. However, capital cost is high and grain near air inlet may be over-dried.

**Grain stirrers** are mobile augers mounted on gantries, which traverse the grain to mix dry and un-dried layers. This effectively speeds the drying front progress and reduces risk of deterioration near the grain surface.

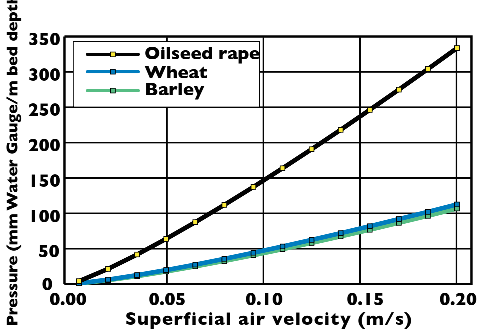
**Vertical aeration** is sometimes used to dry grain. However, duct size and spacing need considerable modification compared with cooling systems. If fans blow, heat can be added to allow drying to a safe moisture content. To minimise the risk of ochratoxin A production, this technique should only be used with grain below 18% mc.

### Strategies for managing fans and heaters

| Strategy | Advantages | Disadvantages |
|---|---|---|
| Fans run continuously, no added heat. | Low capital cost.<br>Keeps grain cool even if air is too damp for drying. | Does not reliably dry grain to safe mc due to high ambient rh late in the season. |
| Fans switched on/off depending on mc of wettest grain and air rh:<br>above 20% mc – 100% rh<br>18–20% mc – 83% rh<br>16–18% mc – 72% rh<br>below 16% mc – 62% rh | Controls costs when no drying is possible. | Extends drying time in damp weather which may allow spoilage. Over-drying near air inlet is likely. |
| Fans run continuously, heater switched on/off depending on air rh. | Air rh can be reduced to allow drying in damp weather.<br>Electric heating during off-peak hours can reduce energy costs. | Moist grain becomes warm allowing faster spoilage. Over-drying near air inlet is likely. |
| Complex computer-modelled strategies. | Control running costs, maximise drying capacity and avoid over-drying. | Not yet fully developed or proven. Controller cost may be high. |

**Near-ambient drying requires fans and ducts capable of delivering at least 20 times the airflow of cooling systems.**

4 DRYING

| ISSUE | ACTION |
|---|---|
| **Dryer design**<br>A good design matches the fan to ducts or drying floor as well as grain bed resistance. A fan has a maximum drying power for a given grain depth and mc. | • Fit larger fans to provide the air needed in unfavourable conditions.<br>• Make plans to supplement drying with added heat in a wet harvest. |
| **Grain depth**<br>Spoilage risk increases as grain depth exceeds a fan's design maximum. Airflow will be seriously reduced and drying zone advance will be slowed.<br>For instance, if grain is normally stored at 2.8 m deep, this depth should be reduced by 0.5 m for each percentage point increase in initial grain moisture above 20%. | • Do not pile grain too deep for the fan. Adjust depth of storage in relation to resistance characteristics.<br>• Level grain surface after filling. |
| **Airflow**<br>Drying from 20% mc requires an airflow of at least 180 $m^3$/hour/tonne to reduce moisture by 0.5% a day. Airflow resistance depends on crop and bed depth.<br>**Pressure resistance curves**<br> | • Keep perforations in ducts and/or floor clear.<br>• Check that airflow is adequate. Measure airflow at several points using an anemometer or seek specialist advice.<br>• Do not allow filling auger to discharge in one place for too long as dust build-up will seriously restrict airflow.<br>• Use a grain stirrer to increase airflow and even out moisture content if drying is too slow. |
| **Moisture content**<br>If intake mc exceeds dryer specification, spoilage may occur before the drying zone reaches the wettest grains. The capacity of even a well run dryer falls by 15% for each 1% mc above 20%. | • Use a sampling spear and an accurate means of measuring grain mc to monitor progress of drying zone.<br>• Measure mc above each duct to check for blockages.<br>• Check inside duct with a torch. |
| **Operation**<br>Given an adequate airflow, control of fans and/or heaters is necessary to manage costs and achieve good drying. Several strategies are possible (see box opposite). | • Before harvest, check and calibrate control equipment, especially humidistats. Locate humidistats near fan inlets, not in the ducts. |

# 5 TEMPERATURE

## BACKGROUND

Insect, mite, fungal and mycotoxin development are controlled by temperature. At temperatures found in grain stores, biological activity of insects, mites, fungi and grain itself, doubles for every 10°C rise in temperature.

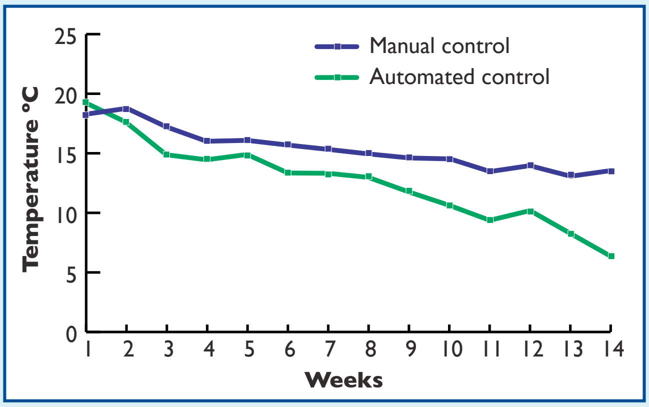
Insect breeding actually stops at low temperatures. Also, less moisture is available for potential pests in cold grain. Therefore, as grain comes into store it should be cooled immediately to prevent insects breeding.

This will even out or equalise temperature gradients and so prevent moisture translocation.

*Automated temperature records*

*Permanent probe arrays can be linked to record keeping software to identify potential problems.*

**Temperatures fall more rapidly and to lower levels when using automatic compared to manual fan control**




**Effect of different temperatures on insect and mite infestation risk**

| Risk | °C | Effects on insects |
|---|---|---|
| | 60 | Death in minutes |
| Least | 50 | Death in hours |
| | | Development stops |
| | 40 | Development slows |
| Greatest | 30 | Maximum development rate |
| | 20 | Development slows |
| | 10 | Development stops but all stages survive |
| | 0 | Insect death in months, movement stops (fungi can still grow slowly in damp grain) |
| | -10 | Death in weeks |
| Least | -20 | Death in minutes, insects freeze |

| Risk | °C | Effects on mites |
|---|---|---|
| | 60 | Death in minutes |
| Least | 50 | Death in hours |
| | | Death in days |
| | 40 | No increase |
| | 30 | Maximum development rate |
| Greatest | 20 | Development slows |
| | 10 | |
| | 0 | Lowest development rate |
| | -10 | Death in weeks |
| Least | -20 | Death in minutes, mites freeze |

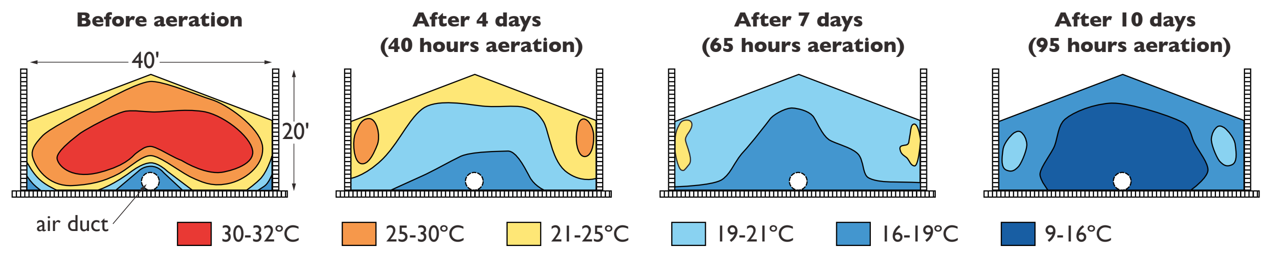
**Grain will be relatively warm post-harvest – ideal for insect breeding and activity. Grain is a good insulator and loses heat very slowly.**

| ISSUE | ACTION |
|---|---|
| **Temperature effects**<br>Cool storage extends grain storage life. It reduces germination loss, maintains baking qualities and protects against infestation.<br>Cool storage permits grain to be stored at higher moisture contents.<br>Lowering the temperature lowers the relative humidity in equilibrium with the mc. This effectively increases storage time.<br>– Hot air in a continuous dryer is likely to disinfest grain. As grain cools naturally it becomes vulnerable to infestation.<br>– Above 40°C, most insects die within a day.<br>– Most insects breed rapidly at 25–33°C. Most insect species do not breed below 15°C but grain weevils can reproduce slowly at 12°C. Below 5°C insects cannot feed and slowly die.<br>– Mites and fungi can increase (although very slowly) down to 5°C in moist grain.<br>– Mycotoxin formation is most likely between 15°C and 25°C.<br>Currently, targets can be achieved in given timescales. However, if autumns become warmer this may become more difficult to achieve consistently. | ● Reduce grain temperature by low volume aeration:<br>– to below 15°C within 2–3 weeks to prevent saw-toothed grain beetles completing their life-cycle.<br>– to below 12°C within 4 months to prevent grain weevils completing their life-cycle.<br>– to below 5°C by end-December to kill surviving adult insects and to prevent mites increasing *(malting barley should not be cooled below 10°C - a practice which may increase the risk of infestation)*.<br>– when grain is moist, eg 15–18% mc, while it awaits drying due to harvest backlogs.<br>EXCEPTION<br>Dry **high moisture** content grain (at or above 18% mc) **immediately** to prevent mycotoxin formation.<br>● Monitor temperature regularly *(every few days until target temperatures are reached, and then weekly)*. |
| **Causes of grain heating**<br>When warm air from the centre of a bulk or bin meets cold grain at the surface, condensation may occur. Moisture at the surface or in damp pockets in the bulk will encourage moulds, heating and sprouting.<br>Developing grain weevils may also generate heat. | ● Aerate grain immediately post-harvest to even out temperatures.<br>● Check temperatures regularly across the bulk – particularly areas furthest away from the duct in a blown aeration system or closest in a suction system.<br>● Cool intermittently, even when grain temperature has fallen, to counteract 'hot-spots' developing. |

# 6 COOLING

## BACKGROUND

### How cooling progresses through a grain bulk




Grain must be cooled rapidly by blowing cooler ambient air through a warmer grain bulk. As this differential temperature increases, cooling rate accelerates. Using low volume aeration (c. 10 $m^3$/hour/tonne or 6 $ft^3$/min/tonne) a cooled 'front' moves slowly through the grain over a period of weeks until the grain is almost uniformly cool.

The first target is to cool the grain to below 15ºC within a fortnight, to prevent saw-toothed grain beetles developing, and then to below 12ºC as quickly as possible to prevent all insects breeding (150–200 hours of aeration).

Blowing ambient air through the bulk is a low cost way to cool (5–10p a tonne). Fans are most efficiently controlled automatically. Differential thermostats measure temperature of grain and ambient air. Fans are switched on when the ambient temperature falls below that of the grain. A differential setting of 4–6ºC provides the most rapid and cost-effective cooling. A differential thermostat installation (costing £300–£600) may be used to control fans in a nest of bins or in a flat store.

Automated temperature monitoring systems may also be used to control fans through relays. A timeswitch allows further efficiency through use of off-peak tariffs. Alternatives to differential thermostats include timeclocks, conventional thermostats and manual control. Using a differential thermostat will ensure most efficient grain cooling.

### Damp air and cooling – a myth

Farmers lose many opportunities to cool grain due to the misconception that blowing damp air will increase grain moisture. In fact, if **blowing** with cooler air (4–6ºC differential), it is not possible to dampen grain.

Thirty years' experience shows that grain around 15% mc usually loses 0.25–0.5% mc during 150–300 hours of aeration with cooler air at recommended rates in a normal storage season. **It does not become damp**.

The only circumstances in which grain may become more damp from blowing require combinations of: excessive aeration rates; very dry grain; condensation around ducts in spring; rain driven into uncovered external fans; successive days of condensing fog.

**Sucking** air through grain may increase natural dampening at the grain surface during winter. This dampening front may extend to one-third of grain depth.

### Vertical aeration

Cooling is just as effective through vertical as through horizontal ducts. Capital cost is lower and risk of damaging ducts during unloading in flat stores is reduced. Blowing air into the duct will cool 20% more grain than sucking. Depending on grain depth, spacing ducts 4–8 m apart should be suitable for an average flat store of cereals.

### Upward versus downward aeration

Blowing air up through grain is preferable to sucking air down because:

i. blowing improves air distribution
ii. 'problems' rise to the surface
iii. fan heating reduces rh of blown air
iv. warm, damp air is flushed from the building
v. cooling can start as soon as ducts are covered.

Suction can be useful if:

i. condensation on the inside of roofs is a problem, although good ventilation can overcome this *(NB Suction may dampen grain surface layers)*
ii. there is a risk of water entering aeration ducts
iii. grain depth is so great that excessive temperature rise would occur with blowing.

**Grain must be cooled rapidly to reduce relative humidity and prevent pest increase. Much less air is needed to cool grain than to dry it.**

| ISSUE | ACTION |
|---|---|
| **Airflow**<br>An airflow of about 10 m³/hour/tonne is needed for cooling taking into account air volumes, insect breeding rate and hours of cool air available post-harvest.<br>Fans need to provide sufficient pressure to overcome resistance due to crop, depth and duct characteristics.<br>Ducts need to be of sufficient diameter and have sufficient perforated area to minimise resistance to the required airflow. | ● Use an anemometer to measure airflow in a measuring duct of appropriate diameter and length placed in front of or after the fan.<br>● Alternatively use a commercial service.<br>● Do NOT use a floatmeter. This is only used for measuring airflow in an ambient air drying system.<br>● Ensure cooling capacity is adequate for depth of crop stored.<br>● Ensure fan power and duct size are adequate for stored crop. Seek specialist advice. |
| **Air volumes for cooling**<br>A bulk drying system used for cooling will achieve the same temperature reduction in a tenth of the time taken by low volume aeration. Careful monitoring is needed to prevent moisture re-deposition. Fan temperature rise may limit cooling. | ● Use appropriate fan sizes, speeds and aeration times for cooling.<br>● Reduce cooling time by 90% if using a bulk drying fan.<br>● Monitor hours to avoid dampening and limit costs. |
| **Timing**<br>Aeration takes time to cool grain effectively. However, there are always adequately long cool periods after harvest in the UK.<br>Stores are normally designed for cereals. Oilseed rape has a much higher resistance to airflow *(see Section 13)*. | ● Start cooling immediately, as beetles quickly begin to breed.<br>● Monitor grain temperatures *(every few days until target temperatures reached, then weekly)*. |
| **Cooling costs**<br>Cooling costs relate directly to hours of aeration. | ● Install an hours meter if fan is controlled automatically.<br>*or*<br>● Manually record hours fan runs. |
| **Troubleshooting**<br>– Grain does not cool at all<br>– Very slow cooling<br>– Uneven cooling | ● Use a probe to monitor temperature at several depths to ensure cooling is even.<br>● Check fan is running and turning in correct direction. Check ducts are not blocked. Check control system and differential thermostat setting.<br>● Investigate airflow rates. Use larger fan(s) or restrict number of ducts blown at any time.<br>● Check ducts are not blocked. Look for isolated faults in a multi-fan system. |

# 7  INSECTS

## BACKGROUND

Some insects are specialised pests of stored foodstuffs, including grain. They damage and contaminate grain but do not infest UK field crops.

Beetles and moths only breed at relatively high temperatures. Cooling significantly slows or prevents development of problems in stores.

Grain weevils were the traditional pest of stored grain in the UK because they bore into grain, and can overwinter. The saw-toothed grain beetle, a tropical species, probably became more dominant with the advent of the combine harvester which damaged grain sufficiently to allow feeding, while the continuous dryer raised the initial temperature of stored grain.

Psocids, winged or wingless booklice, are often conspicuous in traps or running along structures. Their moisture requirement is similar to that of mites, although they are more persistent in dry conditions. It is not known if they damage grain directly.

There may be a succession of insect infestations within a store. Weevils breed at relatively low temperature. However, activity of the last larval stage can raise grain temperature locally and damage grain sufficiently to allow saw-toothed grain beetles to breed. Further grain temperature increase encourages rust-red grain beetles. Mould-feeding beetles, mites and booklice may follow as moisture content increases.

**Insect breeding requirements and possible rates of insect increase**

| Species | Common name | Breeding temperature (°C) | | Maximum monthly increase |
|---|---|---|---|---|
| | | Minimum | Optimum | |
| *Cryptolestes ferrugineus* | rust-red grain beetle | 23 | 32–35 | x 60 |
| *Oryzaephilus surinamensis* | saw-toothed grain beetle | 21 | 31–34 | x 50 |
| *Sitophilus granarius* | grain weevil | 12 | 26–30 | x 15 |
| *Ptinus fur* | white-marked spider beetle | 10 | 21–25 | x 2 |
| *Endrosis sarcitrella* | white-shouldered house moth | 10 | 24–26 | x 30 |
| *Hofmannophila pseudospretella* | brown house moth | 13 | 24–26 | x 2 |

### Other insect sources

A few insect species can fly in to stores during hot weather. These can cause grain to be rejected, even when storage conditions prevent insects completing their life cycles in the store.

### Detection

Insects are relatively small (3–6 mm) and difficult to find. As more samples are taken *(see Section 14)*, chances of detection increase. Even a single insect in a 1 kg sample may represent potentially serious infestation.

### Control

Prevention, using cooling and drying, is preferable to chemical control. However, if monitoring shows infestation is present or levels are rising, pesticide use is justified *(see Section 11)*.

**Insects contaminate and cause direct damage to stored grain. The trade does not tolerate insect pests so it is important to identify, monitor and control them.**

7 INSECTS

| ISSUE | ACTION |
|---|---|
| **Field insects,** eg clover weevil can occur in small numbers in newly harvested grain, but cause little damage and die out quickly in store. However, misidentification by purchasers may still cause rejection. | • Identify insects accurately and seek confirmation (preferably in writing) of pest status. |
| **Primary storage insects** (beetles and moths) invade grain from previous harvest residues, are specialised for the grain storage environment and breed at low moisture content and relatively low temperature (see box opposite).<br>A few species, eg grain weevil develop inside grain making early detection difficult. | • Monitor stored grain for insects. Ensure temperature and mc are low enough to suppress breeding.<br>• Consider physical control techniques, eg cleaning which may be effective but are demanding on resources.<br>• Treat when detected. Emerging adults may indicate established infestation.<br>• Assess the effectiveness of treatment. |
| **Secondary storage insects**, eg fungus feeders, spider beetles and booklice may invade grain from nearby sources, eg haystacks. They only damage poorly conditioned or already infested grain. Occurrence is seasonal and populations build up slowly. | • Monitor for, and remove potential sources of, such pests.<br>• Practise good hygiene.<br>• Consider applying control measures. |
| **Beneficial insects** (predators of storage pests) occur in stores or on grain. Their effectiveness against insects is limited and grain may be rejected if any insects are found. | • Monitor stores and grain.<br>• Identify beneficial insects. They may indicate primary pest infestations that require control. |
| **Resistance to pesticides** makes some insects, eg saw-toothed grain beetle hard to control. This does not mean that they cannot be controlled by admixture or residual treatments. Developing resistance may reduce the effective life of residual treatments or increase the time taken to achieve control. | • Avoid resistance build-up.<br>• Focus on non-chemical means – cooling grain will reduce risk of infestation and insect survival.<br>• Use chemical treatments as a last resort.<br>• Consider fumigating infestations of resistant pests.<br>• Apply pesticides correctly – resistance only develops if pests survive treatment. |

# 8  MITES

## BACKGROUND

Generally less than 0.5 mm long, pale coloured and eight legged, mites are ubiquitous. They feed on a great variety of materials. They lack effective waterproofing, dry out easily and die at low rh. Most do not breed at below 65% rh.

Storage mites can breed very rapidly under favourable conditions. Several million have been found in 1 kg of stored foodstuff. Mites are strongly allergenic, although most people and animals only show allergic reactions when in contact with very large populations of mites.

Mites can cause direct damage and taint stored grain. They may carry fungal spores and bacteria such as *Salmonella*. Mites have been detected in a significant percentage of cereal-based foodstuffs. Resistance to common organophosphorous grain protectants is now widespread and control failures are likely.

### Common species

- *Acarus siro*, flour mite generally lives inside grain and damages germ. The limits for complete development are 2–30ºC at above 60–65% rh. At 25ºC and 90% rh it can multiply sevenfold in one week.
- *Lepidoglyphus (Glycyphagus) destructor*, cosmopolitan food mite is generally found on the grain surface and around debris. Its growth limits are similar to *A. siro* but it only has a fourfold weekly increase at 25ºC and 90% rh.
- *Tyrophagus putrescentiae*, mould mite requires damper, warmer conditions often in association with fungi. Its minimum requirement is 7–10ºC and the most rapid development occurs at 32ºC, 98–100% rh. A close relative, *T. longior*, is more common in cooler UK conditions.
- *Cheyletus eruditus*, a predatory species (particularly on *A. siro*) develops down to 55% rh. It increases one to fourfold each week between 10ºC and 30ºC but can survive for 6 months at 0ºC. Higher temperature and lower moisture requirements means it usually peaks in summer during prolonged storage. Its presence indicates pest problems in store. *Cheyletus* is naturally very tolerant to the OPs used to control grain pests.

### Control methods for mites

| | Control option | Advantages | Disadvantages |
|---|---|---|---|
| **Physical** | Dry cereals to less than 14.5% mc; rapeseed to 7.5% | No residues | Higher drying cost<br>No residual control if mc rises |
| | Turn and clean grain as required | No residues and low cost | Risk of taint from cleaning and allergens still present<br>No residual control |
| | Cool grain to below 5°C | No pesticide residues and low cost | Effectiveness depends on time of year and ambient temperatures |
| **Chemical*** | Apply permitted chemicals on intake | Easy to achieve | Relatively costly – may be short-lived on warm grain<br>Cannot be used for oilseed rape |
| | Apply diatomaceous earth to surface | Easy to achieve | Slow in action and must be combined with cooling and drying |
| | Fumigation | Rapid treatment<br>Requires no farm labour | Requires specialist contractor<br>Storage situation may make it difficult to achieve<br>More costly<br>Effective sealing can be difficult<br>No residual protection |

*** Check the acceptability of any treatment with potential buyers.**

**Storage mites are extremely small but widely distributed. While difficult to detect when present in low numbers, they can lead to increased risk of rejection.**

| ISSUE | ACTION |
| --- | --- |
| **Prevention**<br>Mites breed very rapidly and can survive unfavourable conditions as "resting stages".<br>Mites damage grain directly by eating the germ or hollowing out oilseeds. For grain sold to intervention there is a zero tolerance of mites.<br>In practice it is not possible to exclude mites from stores. However, thorough store preparation minimises "carry-over".<br>Mites often occur in large numbers in debris. They are indistinguishable from dust to the naked eye. | ● Dry cereals to below 14.5% mc and oilseed rape to below 7.5% (in equilibrium with an rh of 65% or less at a temperature of 15°C).<br>● Aerate to cool to below 5°C.<br>● Monitor store structure using mite traps. Look particularly for heavily infested areas. |
| **Surface moisture**<br>After drying, grain surface mc will increase during the winter months. Mite populations will build up at the surface. Storing grain below 13% mc will ensure that the risk of mite population build-up is negligible.<br>Mite numbers will decline naturally as the surface mc declines in the spring. | ● Store grain as dry as possible.<br>● Monitor mc of grain surface during winter and spring using traps, or by sieving a spear sample.<br>● Apply DE, where accepted by buyer, to grain surface to prevent/control infestations. |
| **Control**<br>A single control option is unlikely to be sufficient.<br>**Physical**<br>Grain can be dried and cooled to reduce risk of mite infestation.<br>Conveying and cleaning combined kills 75% to 90% of mites. They are crushed by moving grain, then sieved or aspirated by the cleaner. However, mites inside the grain germ survive and populations can build up quickly again, so this only offers a temporary measure.<br>**Chemical**<br>Chemical control should only be used when grain cannot be dried and cooled. OP dusts are no longer available for top-dressing. Mite numbers will decline naturally as the surface mc declines in the spring. | Ideally use combinations of physical control methods in preference to chemical ones (see box opposite).<br>**Physical**<br>● Re-dry grain.<br>● Turn and clean grain.<br>● Consider applying DE if permitted, to control mites in cooled grain *(see Section 11)*.<br>**Chemical**<br>● Admix cereals with an approved pesticide at intake if a quick sale is required to a zero tolerance market<br>*Recommended application rates of approved OPs will not control predatory mites.*<br>● Apply surface treatments to control some mite species. Low ambient winter temperatures and/or resistance may reduce pesticide efficacy.<br>● Fumigate with phosphine. Generally two treatments separated by 5 to 10 days are required as eggs are tolerant. Research shows that a single fumigation can be effective. |

# 9 PEST IDENTIFICAT

## Commonest primary pests

**Can increase rapidly and damage grain stored at 14.5% mc.**

### Grain weevil

*Sitophilus granarius*

Develops inside the grain. Causes heating.

Difficult to find.

### Saw-toothed grain beetle

*Oryzaephilus surinamensis*

Only develops on damaged surface of grain.

Very active and easy to trap.

### Rust-red grain beetle

*Cryptolestes ferrugineus*

Penetrates grain through minute cracks.

Can fly in hot UK summers.

## Other primary pests

**Occasionally found on UK grain but require high temperatures and do not overwinter well.**

### Rice weevil

*Sitophilus oryzae/zeamais*

Mainly associated with imported feedstuffs. Can move into stored grain. Eggs laid inside grain.

### Lesser grain borer

*Rhyzopertha dominica*

Eggs laid on grain surface, larvae burrow inside to develop.

### Rust-red flour beetle

*Tribolium castaneum*

Requires a high proportion of damaged grains to thrive. Frequently found in animal feed mills.

## Secondary pests

**Cannot complete their life-cycles at 14.5% mc or below. Feed primarily on fungi. Can invade grain stores in large numbers from outside and feed directly on grain.**

### Hairy fungus beetle

*Typhaea stercorea*

Often associated with stored straw and hay, as well as damp residues.

### Foreign grain beetle

*Ahasverus advena*

Increasingly common in UK. Very mobile and a common cause of rejection.

### Fungus beetles

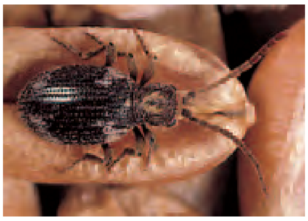
eg *Cryptophagus* species

Frequent in damp, mouldy residues and can wander into stored grain.

### Australian spider beetle

*Ptinus tectus*

Seldom found in UK grain, but survives in structure of warmer stores.



### White-marked spider beetle

*Ptinus fur*

Numbers can take years to build up. Can survive long periods in an inactive form.

### Plaster beetle

*Lathridiidae*

Very small black beetles which flourish in damp, mouldy residues.

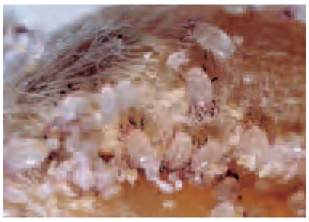
## Insect stages

### Beetle larva

Jaws often distinguish these from moth larvae.

## Pest mites

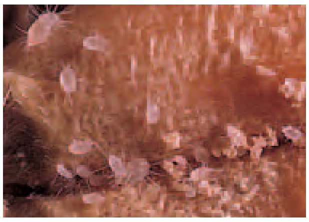
**Normally only a problem on damper surface of dry bulk.**



### Flour mite

*Acarus siro*

Indicates bulk mc is higher than recommended. Internal feeder which can build up massive populations.



### Cosmopolitan food mite

*Lepidoglyphus destructor*

Surface feeder usually present in low to moderate numbers.

### Grainstack mite

*Tyrophagus longior*

Initial infestations often occur during bulk drying operations. Requires high mc and temperature.

## Predatory & other mites

**Large numbers indicate high temperatures and previous infestations.**

### Predatory mite

*Cheyletus eruditus*

Preys on pest mites as well as small beetle and moth larvae.

### Gamasidae

Long-legged fast movers may prey on pest mites. Individuals may also be blood feeders on rodents

## Moths

**May be seen flying in summer. Webbing produced by larvae may clump grains together. Mainly occur on surface of bulk, also infest and breed in debris.**

### Brown house moth

*Hofmannophila pseudospretella*

Often associated with animal feeds.

### White-shouldered house moth

*Endrosis sarcitrella*

Slow to develop in old grain or feed residues.

### Moth larva

Distinguished from beetle larvae by dark head capsule.

## Booklice

**Considerable numbers may build up at grain surface, mainly in winter. Can be clearly seen running over storage structures.**

### – wingless

Require damper conditions, ubiquitous in UK.

### – winged

Can be found in spectacular numbers, especially around edges of grain bulk. Pest status not clear.

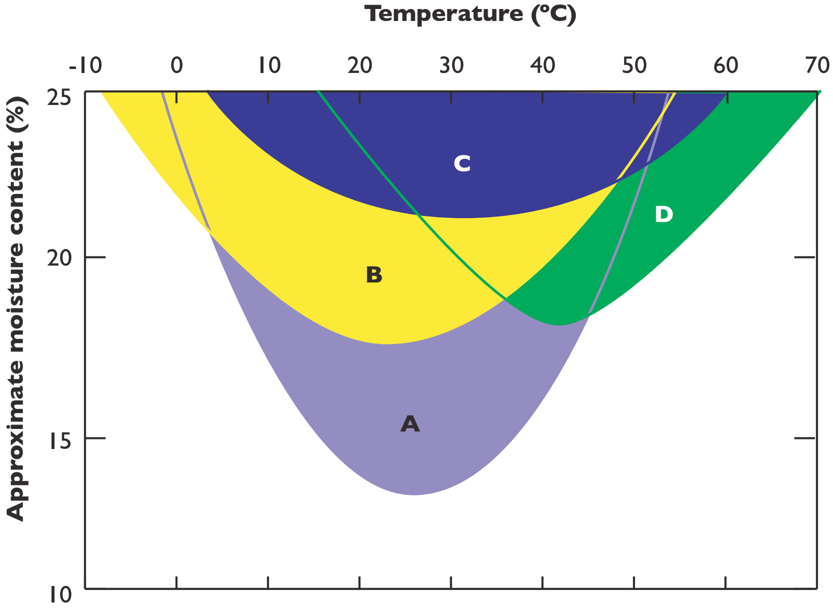
# 10 FUNGI

## BACKGROUND

The species of fungi which infect stored grain do not infect growing crops.

Storage fungi can grow on grain from about 14.5% mc upwards. They cause heating and germination loss. Some produce potent toxins. However, mycotoxin production is only likely from 18% mc and above. The drier and cooler the storage conditions, the safer grain is from fungal attack as shown in the figure.

**Different types of fungi thrive at different moisture contents and temperatures in stored grain**




**A –** *Aspergillus* species which may damage germination and cause slow heating.

**B –** *Penicillium* species, including those that produce mycotoxins.

**C –** Advanced decay/field fungi, eg *Fusarium* species and heating organisms, eg *Absidia* species which may be pathogenic causing, for instance, farmers' lung.

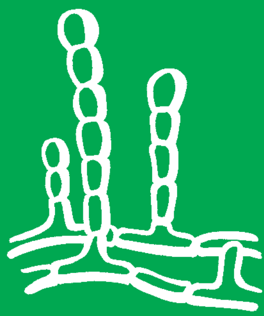
**D –** Thermophilic fungi, which thrive at very high temperatures, such as occur in compost bins.

**Options for preventing fungal attack in store**

| | Advantages | Disadvantages |
|---|---|---|
| **Drying** | Also controls mites<br>Grain not killed<br>Permanent protection | Capital cost of heated-air drying<br>High running costs |
| **Airtight** | Grain rolled for feed does not need dampening | Grain killed – only usable for animal feed<br>Carbon dioxide hazard<br>Air entry during unloading may allow deterioration |
| **Caustic soda** | Digestibility improved<br>Need for rolling eliminated | Grain killed – only usable for animal feed<br>Corrosive – safety measures required |
| **Organic acids** | Saves cost of drying | Grain killed – only usable for animal feed<br>Corrosive – safety measures required |

EU maximum permissible limits for aflatoxins in cereals came into force on 30 June 1999. However, these mycotoxins rarely occur in UK-stored grain. In 2002, EU regulations set maximum permissible levels for ochratoxin A at 5 parts per billion (ppb) for cereals. Where grain is stored above 18% mc, these levels can be exceeded in just two weeks.

**In the right conditions fungi develop rapidly causing loss of germination, discolouration, tainting with off-odours, and rejection.**



## ISSUE | ACTION

### Detection

Visibly mouldy grain will be already tainted and mycotoxin production may have started. Fungal mycelium and spores may be seen. Some species of mites feed on fungi and may mask evidence of fungal growth. Absence of visible mould does not guarantee freedom from mycotoxins.

- Monitor grain mc and temperature. Increasing moisture and/or temperature indicate fungal or insect activity.
- Do not sniff mouldy grain – spores can cause “farmers’ lung”.

### Physical treatment

Storage fungi grow within a narrow range of moisture and temperature. They continue growing slowly at near 0ºC, so cooling alone is insufficient for long-term storage of damp grain. No storage fungi will grow below 14.5% mc.

- Dry grain to 14.5% mc or below.

*or*

- Store grain in an airtight silo.

### Chemical treatment *(animal feed only)*

– Caustic soda-treated grain swells making silo storage impractical. Treatment offers no long-term protection against insects or mites.

– Propionic acid allows storage of damp grain but offers no long-term protection against insects or mites.

- Apply caustic soda solution – either 30–45 g solid, or 47% solution.

*or*

- Apply propionic acid at 5.5 L/tonne at 16% mc, to 14.5 L/tonne at 32% mc.

### Mycotoxins

Mycotoxins formed before harvest, such as *Fusarium* toxins, are stable and likely to remain during storage.

Ochratoxin A (OA) can be produced by *Penicillium verrucosum* in UK-stored grain. Other mycotoxins may also be formed in store.

Mycotoxins are produced at a slightly higher mc.

– *Penicillium verrucosum* grows above 17% mc and between 5ºC and 40ºC.

– Highest risk is associated with floor-dried bulks (near-ambient drying).

– EU maximum permissible level for OA in cereals is 5 ppb for cereals.

– Sampling and analysis for mycotoxin presence is expensive.

A rapid test for OA is being developed with HGCA funding.

- Dry wet grain immediately to prevent OA production which occurs above 18% mc.
- Use ventilation to cool damp grain, which is temporarily stored at lower mc. This will not prevent some deterioration from fungi and mites.

*Incomplete or slow drying can lead to mouldy grain and mycotoxin production.*

ALWAYS TAKE APPROPRIATE SAFETY PRECAUTIONS WHEN HANDLING GRAIN OR USING CHEMICALS.

# 12  RODENTS & BIRDS

## BACKGROUND

Legislation, codes of practice, and quality assurance schemes all require rodent and bird management programmes as part of good grain storage. Principal risks from these pests are disease transmission, grain spoilage and contamination, and structural damage.

Pest exclusion is the primary aim of management programmes, backed up where necessary by approved lethal control measures.

### Rodents

Approved rodenticides may be used, provided non-target animals cannot access the poisons. Certain lethal, or 'live capture', traps can also be used.

Poisons can be either acute (fast-acting) or chronic (delayed action). The latter are the most commonly used.

Chronic baits usually have an anticoagulant action. Anticoagulant active ingredients fall into two sub-groups: first and second generation; the latter being more potent. Anticoagulants cause haemorrhaging leading to death several days after bait consumption.

**Examples of the main ingredients of commercially available rodenticides**

| First generation | | Second generation | |
|---|---|---|---|
| warfarin | diphacinone | difenacoum | bromadialone |
| chlorophacinone | coumatetralyl | brodifacoum* | flocoumafen* |

* *indoor use only*

A challenge is to ensure that bait, rather than readily-accessible foods, is eaten. Mice and rats respond differently to baits, in terms of behaviour and also tolerance:

- Rats are 'shy' of new objects in their surroundings (neophobia), while mice are more inquisitive.
- Mice feed more erratically than rats. Therefore many more bait points are required for mouse control.
- Anticoagulants are more effective against rats than mice.
- Mice are generally insensitive to first generation anticoagulants. Calciferol-based rodenticides (eg Sorexa CD) or second generation anticoagulants (eg brodifacoum or flocoumafen) should be used.
- Rats have to drink water to survive; mice do not.
- Rats usually migrate into stores during autumn/early winter; mice are resident year round.

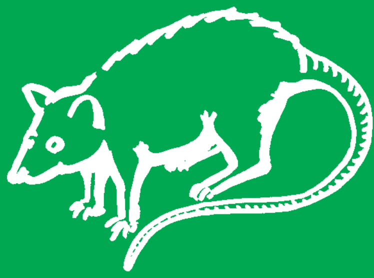
Resistance has developed in some UK rat populations and can lead to control failures, even when an approved product is used correctly. Failure, or slower action, of previously effective treatments may indicate resistance. If you suspect resistance is present, contact Defra or CSL for specialist advice.

**For more detailed information on controlling rats and mice in and around grain stores see *Rodent control in agriculture – a guide* (2002).**


### Birds

All birds are protected under the Wildlife and Countryside Act, 1981. However, listed pest species can be killed or taken for specific purposes including protecting public health and preventing significant financial loss. General licences allow certain species – eg feral pigeons, collared doves, starlings and house sparrows – to be killed, taken or their eggs and nests destroyed. Licence enquiries should be made to Defra.

Effective proofing to prevent bird access is usually adequate.



## Vertebrate pests threaten stored grain through feeding, contamination and struc-



| ISSUE | ACTION |
| --- | --- |
| **Rats & mice**<br>Rodents enter stores, damage and contaminate food and feed.<br>A juvenile mouse can enter via a gap of only 5 mm. | • Prevent entry by effective structural proofing.<br>• Remove potential harbourages. |
| Rats normally migrate into buildings during late autumn and winter. | • Monitor stores and environs carefully during autumn and winter.<br>• Respond immediately to signs of rat activity. |
| Rats tend to avoid new objects (eg a bait container) and are wary of any novel food. | • Leave bait boxes in place for several days/weeks before moving to alternative locations. |
| Rats require access to 'free water' | • Eliminate water sources where possible. |
| Some rat populations are insensitive to several anticoagulant baits. | • Seek specialist advice to determine if resistance is a problem, when control is difficult to achieve.<br>• Consider alternative control strategies. |
| Mice are inquisitive and very agile animals. | • Place baits at many locations.<br>• Use small amounts of bait at each location. |
| Rodenticides may present a risk to non-target animals. | • Protect non-target animals from baits.<br>• Consider using specialist bait boxes or containers. |
| **Birds**<br>Birds contaminate grain. Infestations can cause direct (feeding) losses. | • Prevent entry by proofing.<br>• Use appropriate mesh or plastic curtains to 'seal' even larger spaces. |
| Birds are attracted by food, eg spilled grain. | • Sweep up any grain spillage. |

ENSURE RODENTICIDES ARE USED SAFELY AND CORRECTLY. ALWAYS READ THE LABEL AND FOLLOW INSTRUCTIONS.

# 13 OILSEED RAPE

## BACKGROUND

### Effects of seed size on airflow

Small seed size means grain flows very easily. This can lead to leakage and blocked ducts which can restrict airflow for drying and cooling.

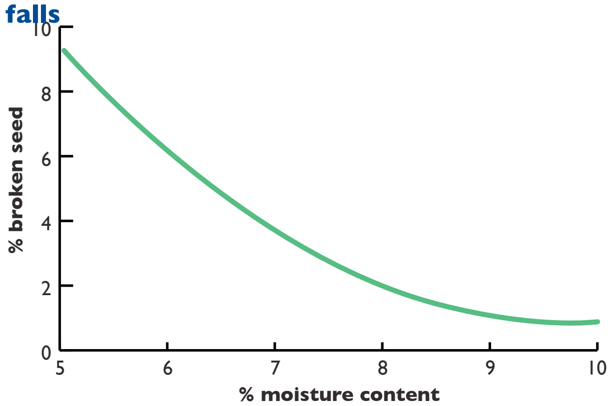
Even when properly contained, the small seeds of oilseed rape offer increased resistance to airflow so bulk depth should be reduced, or fan capacity increased. A survey has shown that many storekeepers consider rapeseed and cereals in the same way. In fact each crop requires different treatment.

### Moisture content, seed breakage and oil content

The high oil content means that the relative humidity: moisture content relationship is very different from that of cereals *(see Section 2)*. **The safe mc for storing rapeseed is about half that of cereals.**

However, rapeseed becomes very brittle at low mc so over-drying can be a problem. The proportion of broken seed increases rapidly below 7% mc; and seed under 6% mc is not accepted by crushers.

**Seed breakage rises as moisture content falls**



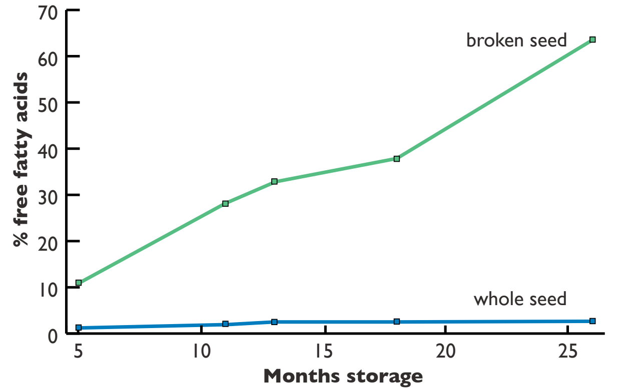

Seed must be handled carefully as free fatty acid (ffa) content increases rapidly in broken seed. This is important as high ffa may cause oil degradation after crushing.

Seed must not be allowed to heat up before drying. High temperatures can result in burnt seed and high ffa levels.

There is little lee-way between the safest mc for prolonged, stable storage (7.5–8%) and the lowest acceptable mc (6%). Good practice requires careful drying and accurate moisture meter calibration.

Drying to below the 9% mc contract level may incur extra cost. However, a small increase in oil content will partly offset this.

**Free fatty acids increase rapidly in broken seed during storage**




### Safe drying temperatures and moisture

| Crop usage | Safe drying temperature: Seed moisture content below 10% mc | Safe drying temperature: Seed moisture content above 12.5% mc |
|---|---|---|
| **Seed crop** | 49°C | 43°C |
| **Commercial (mixed during drying)** | 82°C | 71°C |
| **Commercial (unmixed during drying)** | 71°C | 60°C |

*Source: www.agric.gov.ab.ca/crops/canada/storage.html*

**Storing oilseeds presents different challenges to cereals. Crops should be dried and cooled in shallower bulks, then stored at a lower moisture content.**

| ISSUE | ACTION |
|---|---|
| In rapeseed 7.5%–8% mc is in equilibrium with 65% rh. This is below the minimum requirement for mite and mould development. | • Dry seed to 7.5–8% mc for safe storage.<br>• Dry and cool high mc grain immediately. |
| Oilseed rape seed becomes brittle if:<br>– dried to a very low mc<br>– dried too fast<br>– air temperatures used are too high. | • Match air temperature to moisture content of seed being dried *(see safe drying temperatures opposite)*.<br>• Manage drying temperature to avoid burnt seed. |
| Storage mc is related to change in ffa content, as seed at below 6 % mc is very brittle. | • Handle oilseed rape very carefully, eg ensure augers run full.<br>• Regulate drying so that no seed is below 6% mc. |
| Slow drying and/or cooling will encourage mites and mould growth which may lead to mycotoxin formation.<br>Reduced airflow, compared to that normally used for cereals, MAY be adequate for cooling dried rapeseed as the threat from insects is less.<br>Low temperatures help protect against ffa increases. | • Reduce bed depth by 50–70% if using systems designed for conventional cereals storage.<br>• Consider purpose-built storage for oilseeds. Note, this is costly and may be impractical.<br>• Cool grain rapidly after drying. |
| The merchant grain beetle, *O. mercator* and the saw-toothed grain beetle, *O. surinamensis* can establish small populations. No insecticides are available for admixture. | • Dry and cool oilseed rape properly. |
| Mites develop rapidly in damp seed. They damage seed, raise ffa levels and may directly reduce oil yield. | • Store seed at 7.5% mc (65% erh).<br>• Consider phosphine treatment if mite infestations develop in incorrectly dried grain. |
| Immature seed can cause heating, rapid deterioration of the oil fraction and affect oil colour, making it less acceptable. This has been 'flagged' as a commercial concern. | • Manage proportion of green seeds by:<br>– leaving seeds in the swath for four days<br>– drying at safe temperature<br>– aerating store intermittently to remove generated heat. |
| Rapeseed is very likely to leak from most bins. | • Seal bins with tape to contain rapeseed.<br>• Cover ducts with hessian to prevent leakage of rapeseed. |

# 14 MONITORING

## INTRODUCTION

### Monitoring and sampling

In the first edition of '*The grain storage guide*', 1999 the **sampling** section covered two related aspects:

- determining grain quality for end use, eg germination for malting barley, protein for milling wheat, oil and free fatty acid for rapeseed.
- monitoring physical and biological aspects of grain and the storage environment before and during storage.

In 2003, a specific HGCA publication '*Grain sampling - a farmer's guide*' focused on grain quality sampling. Therefore, the information below focuses on monitoring to preserve storage quality.

Monitoring during storage requires a wider range of techniques than sampling for quality. Stored grain and oilseeds are monitored to establish if deterioration is occurring; or whether drying and cooling are effective and targets achieved.

Changes to grain quality can be predicted by monitoring physical conditions and pest incidence. Monitoring thus provides early warning of problems. It also provides decision support about when grain should be sold and/or management actions needed. Records from monitoring ensure compliance with assurance schemes.

Monitoring is an integral part of grain storage at several stages and for several purposes. Where appropriate, section 14 cross-refers to the relevant section in this guide.

**Sampling before storage to determine grain quality is summarised in the HGCA booklet *Grain sampling – a farmer's guide*.**


## BACKGROUND

### 1 PREPARATION

**Clean, empty stores are monitored for insect pests using insect traps and for rodents using bait points.**

**Detecting insects in the empty store allows decisions to be made about need for fabric treatments before grain goes into store.**

### 2 MOISTURE

**Grain moisture content is an important measure. It reflects risk of infestation and moulds.**

### 4 & 6 DRYING and COOLING

**Both ambient-air drying and cooling systems rely on sufficient airflow for targets to be met on time.**

**Drying requires 10 to 20 times the airflow needed for cooling.**

### 5 TEMPERATURE

#### Monitoring equipment

- **Thermocouples**, which are cheap and flexible, may be used for sensor arrays but are less robust than **thermistors** which are usually employed in commercial equipment or installations.
- **Permanent probe arrays** can be interfaced with computers and downloaded into record-keeping software to access problem-solving tools.
- **Alcohol, mercury in glass or bimetallic strip thermometers** cannot be used for remote sensing. Glass thermometers may not be used in grain stores because of the possibility of breakage.

Temperature sensors can be integrated to control fan operation and linked to automatic recording systems.

**Monitoring physical factors from empty store onwards is vital to achieve long-term, stable grain storage.**



| ISSUE | ACTION |
|---|---|
| **Pest monitoring**<br>Invertebrate pests are very small and difficult to detect.<br>Vertebrate pests can go unnoticed. Evidence of past rodent infestations will persist.<br>Treatments should only be used when pests are present. | • Look for signs of insects, mites, rodents or birds.<br>• If insects are not seen, place insect traps in store and examine after seven days (ensure bait bags are not left in the store).<br>• Identify insects accurately.<br>• Monitor rodent baiting stations weekly. |
| Measurements confirm that grain off a hot-air dryer is at the required mc.<br>They also indicate the progress of a drying front with ambient-air or bulk drying. In an upwards (blowing) drying system the slowest drying area will be near the surface and between ducts or between the duct and the store wall.<br>Dry grain can absorb moisture at the surface during winter. | • Locate the drying front by withdrawing samples from different depths, or by probing the slowest-drying column using a moisture spear.<br>• Take samples each month at the surface during winter. |
| Cooling and drying performance depends on the air volume passed through the grain, which is determined by multiplying fan output (measured as $m^3$/hour/tonne) by hours run. Records of fan hours run, or airflow may provide explanations if cooling or drying is slower than expected. | • Use an hours meter and record fan hours weekly.<br>• Calculate air volume delivered.<br>• Check airflow delivered by the fan using a hot-wire or vane-anemometer.<br>• Use a floatmeter at the grain surface to measure drying rate airflows. |
| Measuring temperature indicates if the cooling system is operating properly so remedial action can be taken if necessary.<br>Temperature also indicates infestation risk. The most important temperature to measure is where grain cooling takes longest, eg furthest away from the fan in blowing (upward aeration) systems. This is usually 0.5 m beneath the surface and centrally between ducts. | • Take measurements daily for the first week or two while temperatures fall below 15–20°C.<br>• Take measurements weekly for the first month or two and thereafter monthly.<br>• Ideally use a permanent grid of sensors in large stores.<br>• For smaller bins or heaps, use a portable temperature spear probe, possibly with a moisture sensor.<br>• Do NOT use long metal probes as sensors need to attain stable grain temperature rapidly.<br>• Sample temperatures regularly at the same locations and keep permanent records. |

# 14 MONITORING

## BACKGROUND

### 7 INSECTS

**Detecting insects in grain enables corrective action to be taken before sale. This avoids costly rejection if insects are detected at the point of sale.**

**Detecting insects inside the empty store allows decisions to be made about whether fabric treatments are needed before grain goes into store.**

Insects are relatively small (3-6 mm) and difficult to find. As more samples are taken, chances of detection increase. Even a single insect in a 1 kg sample may represent potentially serious infestation.

To assist monitoring, traps have been developed. These are more than ten times as effective as sampling at detecting insects and mites. They may also be the only effective method of detecting insects in grain bulks where use of spears is restricted.

- **Pitfall traps:** Tie at least 1 m of string to a bamboo cane marker to avoid losing trap. In large stores flag and number canes. Bury trap so that the rim is level with grain surface. If grain falls into trap still examine contents using a sieve to separate out insects or mites. Clean pitfall traps and treat with fluon every 2-3 months.
- **Probe traps:** Tie trap to marker cane by at least 1 m of string. Bury traps vertically to just below surface.
- **PC traps** combine features of pitfall and probe traps. Use in pairs – at surface and 5-10 cm below.
- **Bait bags** containing carob-based aromatic seed mixes are used to assess residual infestations, particularly in empty stores. Bait bags **must** be collected and counted after use.
- **The I-spy insect indicator** (also called a PC floor trap) is a PC trap with a flat base in place of the perspex funnel and enhanced with a lure.

*HGCA funding has developed insect traps which are the most cost-effective way of detecting insects in static bulks.*

*Insect trapping is an integral component of the Assured Combinable Crops Scheme.*

### 8 MITES

**Mites can be monitored by using mite traps or by sieving.**

- **If the moisture content is above 14.5%**, mites will be widespread throughout the bulk.
- **Providing the bulk mc is below 14.5**, mites only usually occur at the grain surface
- **Where the bulk mc is below 13%**, the risk of mite infestation occurring at the surface is negligible.

*Mite trap*

# Monitoring pests assesses effectiveness of control measures.

| ISSUE | ACTION |
|---|---|
| **Traps** are not very effective for quantifying insect infestations but can indicate population trends. Numbers caught are influenced by trap type, species, grain disturbance, temperature and whether grain has been treated with pesticide.<br><br>Insects usually die out during cool storage. If numbers trapped increase consistently there is cause for concern.<br><br>A few insects in a trap do not mean control measures **must** be used. Treatment depends on intended market and stage of storage. | • Lay traps in a 4–5 m grid. Check every week early in the season and monthly thereafter. Leave in place for a week before examination.<br>• Record trap locations. Account for all traps at each monitoring.<br>• Empty pests onto white tray or card to make more visible. Alternatively place insects in a sealable, labelled bag or tube and examine in the office.<br>• Record trap catches. Identify pests accurately.<br>• React to sustained increases in numbers.<br>• Apply treatments, possibly in localised areas.<br>• Use I-Spy insect indicator or bait bags to detect crawling insects on flat surfaces. |
| **Sampling for pests**<br><br>**– at intake**<br>Freshly harvested grain will not contain storage pests.<br><br>Previously stored grain may be infested. | • No action is needed for harvest-fresh grain. Field insects will die out.<br>• Sample before unloading – sieve at least 3–5 kg of grain from each load. |
| **– during storage**<br>Early detection is crucial, but sampling is unreliable. Changes in temperature and moisture may indicate infestation risk. Mites and fungus beetles commonly occur in damper surface layers. | • Use insect traps as the most reliable method of detecting insects *(see Sections 7 & 8)*.<br>• Monitor and record temperature and moisture regularly *(see Sections 2 & 5)*. Investigate areas of change. |
| **– at outloading**<br>Pests must be detected and dealt with before outloading. | • Check samples for insects or mites. Absence of pests is no guarantee of freedom from infestation. |
| Mites often occur in large numbers in debris and are almost indistinguishable from dust. In damp grain, mites are distributed throughout the bulk but in drier grain will be close to the surface.<br><br>Mites are most likely to re-infest a grain surface when it absorbs moisture from the atmosphere in winter. | • Monitor store structure using mite traps. These should indicate higher risk areas.<br>• Sample grain from different depths and sieve through a 1 mm mesh. Examine sievings using a hand lens (minimum x10). Carry out parallel measurement of mc to assess likelihood of further infestation.<br>• Monitor grain surface for mites and control any populations found.<br>• Look for mites in insect traps or by sieving a spear sample of grain. |

# REFERENCES

## HGCA guides

**Rodent control in agriculture – a guide**, 2002

**Grain sampling – a farmer's guide**, 2003

## HGCA Topic Sheets

*Posted free to levy payers on request.*

7 **Integrated grain storage strategies**

8 **Effective phosphine fumigation of grain**

16 **Bulk storage drying of grain and oilseeds**

26 **Sampling grain on farm**

34 **Mycotoxins in stored grain**

53 **Vertical ventilation for cooling grain**

60 **Ensuring good germination in malting barley**

62 **Preventing and controlling mites in stored cereals**

## HGCA Research Reviews (cereals)*

3 **The biodeterioration of stored cereals**

7 **The control of pests in stored cereals**

12 **The occurrence and detection of pesticide residues in UK grain**

13 **The occurrence and detection of moulds, mycotoxins and actinomycetes in UK grain**

15 **Moisture content of cereal grains**

27 **Methods of distributing phosphine in bulk grain**

38 **Bulk storage drying of grain and oilseeds**

42 **Alternatives to organophosphorous compounds for the control of storage mites**

## HGCA Research Review (oilseeds)*

OS6 **Drying and storage of oilseeds**

## HGCA Project Reports (cereals)*

6 **The control of insects in export grain**

7 **Economic analysis of stored product pest control strategies (GPA 'Grain Pest Adviser' expert system)**

24 **Integrated pest control strategy for stored grain**

29 **Commercial grain stores 1988/89, England and Wales. Pest incidence and storage practices (two volumes)**

30 **Improving the effectiveness of pitfall traps for the detection of insect pests in grain**

34 **An assessment of methods of sampling bulk grain**

35 **The reduction of chemical and microbial contaminants in wheat**

40 **Evaluation and development of systems for storing malting barley**

41 **New application methods for the use of phosphine to disinfest bulk grain**

45 **Residues of etrimfos and pirimiphos-methyl in wheat and malting barley stored in ventilated bins**

57 **Integrated pest control strategy for stored grain – surface pesticide treatment of aerated commercial and farm stores to control insects and mites**

69 **The control of insects in export grain by admixture chemicals**

79 **An assessment of practical methods for collecting samples from lorry-loads of grain**

82 **The development of a practical method for removing insects from large samples of grain**

84 **Dormancy in malting barley: studies on drying, storage, biochemistry and physiology**

92 **The potential of near-infrared spectroscopy for the rapid detection of pests in stored grain**

96 **A comparison of methods of applying pesticides to cereal grains before storage**

105 **Control of grain pests with phosphine at temperatures below 10ºC**

113 **The effects of conveying on insects and mites infesting grain intended for export: significance with respect to chemical treatments**

118 **The collection of samples of grain: an assessment of current methods and problems**

122 **Immunoassays for the detection of organophosphorous pesticides on stored grain: assessment of three commercially available kits and recommendations for laboratory and field use**

138 **The development of an integrated grain storage strategy for malting barley**

147 **The development of an integrated management system for stored grain**

149 **Development of a controlled dosing system for methyl bromide fumigation of mills and grain storage structures**

156 **Rapid automated detection of insects and certain other contaminants in cereals**

181 **Strategies for the use of phosphine to combat infestation problems affecting the quality of bulk grain**

196 **A study to determine whether on-floor ambient drying systems are conducive to the formation of ochratoxin A in grain**

201 **Limiting moisture uptake at the grain surface to prevent mite infestation**

207 **Investigation of Fusarium infection and mycotoxin levels in harvested wheat grain (1998)**

208 **A rapid, sensitive, user-friendly method for detecting storage mites**

212 **Testing cereals for mycotoxins: review and assessment of rapid test kits**

230 **Survey of mycotoxins in stored grain from the 1999 harvest in the UK**

231 **Optimisation and validation of a floor trap for the detection of insect pests in empty stores, in bagged stacks and on flat surfaces in the cereal and food trades**

233 **Comparison of pesticide efficacy against insects and mites for grain store structure treatment**

246 **Design of gas distribution systems for cylinder-based low volume phosphine applications to bulk grain**

249 **The efficacy of alternative compounds to organophosphorous pesticides for the control of storage mite pests**

256 **Practical and modelling studies on the use of modified atmospheres for insect and mite control in grain stores**

262 **Design of an integrated machine vision system capable of detecting hidden infestation in wheat grains**

269 **Optimising the performance of vertical aeration systems**

284 **A rapid method for detecting the predominant storage mite species, *Acarus siro*, in the presence of grain**

289 **Practical guidelines to minimise mycotoxin development in UK cereals in line with forthcoming EU legislation, using the correct agronomic techniques and grain storage management**

295 **Development and testing of a sensor to detect microbiological spoilage in grain**

*NOTE: *Project Reports and Research Reviews are available at cost from HGCA.*

## Books

- **Drying and storing combinable crops**, K A McLean, Farming Press, second edition, 1989.
- **Common insect pests of stored food products. A guide to their identification**, Ed. P. Freeman, British Museum (Natural History), Economic Series No. 15.
- **Storage of cereal grains and their products**, Ed: D B Sauer, American Association of Cereal Chemists, 4th Edition, 1992.
- **Stored grain ecosystems**, Eds: D S Jayas, N D White, W E Muir, Marcel Dekker, USA, 1995.
- **Technical bulletin 9. The mites of stored food and houses**, Dr A M Hughes, HMSO, second edition, 1976.
- **"Codes of practice" for quality assurance** – Assured Combinable Crops Scheme (for England and Wales) and Scottish Quality Cereals.
- **Codes of practice for control of salmonella**, MAFF.
- **Pesticides 1999: pesticides approved under the Control of Pesticides Regulations 1985 and the Plant Protection Products Regulations 1995**, MAFF.
- **Integrated management of insects in stored products**. Eds. B Subramanyam, D. Hagstrum, Marcel Dekker USA, 1996.
- **The UK pesticide guide, CAB International** 2003.

## Websites

**HGCA:**
www.hgca.com/research/grain storage

**Maltsters' Association of Great Britain:**
www.ukmalt.com
www.malt.info

**Pesticides Safety Directorate:**
www.pesticides.gov.uk

**Central Science Laboratory:**
www.csl.gov.uk

**US Department of Agriculture, Agricultural Research Service:**
www.ars.usda.gov/is/mb/mebrweb.htm

**Pestweb:**
www.pestweb.com

**Stored Grain Research Laboratory, Australia:**
http://sgrl.csiro.au/default/html

**Alberta Agriculture Food and Rural Development, Canada:**
www.agric.gov.ab.ca/crops/canada/storage.html

**Scottish Whisky Association (SWA):**
www.scotch-whisky.org.uk

**British Beer and Pubs Association (BBPA):**
www.beerandpub.com

## Software

- **HGCA GrainPlan** – an expert system. Available early 2004. Free to levy payers from HGCA.
- **Grain sampling – a farmer's guide**, on CD, 2003.
- **Integrated grain storage manager** – an expert system developed with HGCA and Defra funding. £49.99 (inc p&p) to HGCA levy payers. Tel: 020 7594 6565.

## Legislation

- **Agriculture act 1947**
- **Prevention of damage by pests act 1949**
- **Pests act 1954**
- **Health and safety at work act 1974**
- **Control of pollution act 1974**
- **Spring traps approval order 1975**
- **Wildlife and countryside act 1981**
- **Spring traps approval (variation) order 1985**
- **Food and environment protection act 1985 (part iii)**
- **Control of pesticides regulations as amended 1986**
- **Food safety act 1990**
- **Environmental protection act 1990**
- **Management of health and safety at work regulations 1992**
- **The control of substances hazardous to health regulations 1994**
- **Food safety (general food hygiene) regulations 1995**
- **Wild mammals (protection) act 1996**
- **Biocidal products directive (98/008/EEC)**
- **Plant protection products (basic conditions) regulations 1997**
- **Anon, 2002. Commission directive 2002/26/EC of 13 March 2002 laying down the sampling methods and methods of analysis for the official control of the levels of ochratoxin A in foodstuffs. Official Journal of the European Communities. L75/38 – 43.**

## British and International Standards

| Standard number | | | | Title | International equivalent | |
|---|---|---|---|---|---|---|
| BS | 4317 | Part 3 | (1999) | **Determination of moisture content of cereals and cereal products (routine reference method)** | ISO | 712 |
| BS | 4317 | Part 18 | (1988) | **Determination of hidden insect infestation** | ISO | 6639 |
| BS | 4317 | Part 24 | (1990) | **Method of checking the calibration of moisture meters for cereals** | ISO | 7700-1 |
| BS | 4317 | Part 26 | (1991) | **Measurement of temperature of grain during bulk storage** | ISO | 4112 |
| BS | 6219 | | (1996) | **Test sieves for cereals** | ISO | 5223 |
| BS | 6279 | Part 2 | (2001) | **Storage of cereals and pulses. Practical recommendations** | ISO | 6322-2 |
| BS | 13690 | | (1999) | **Cereals, pulses and milled products. Sampling of static batches** | ISO | 13690 |

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