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Grain storage guide

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Introduction

Compared with selling grain at, or near, harvest, later-sold grain usually receives a higher price (providing market specifications are met). Typically, feed wheat sold for a November movement attracts a £4/tonne premium over the harvest price, with May movement providing a further £7/tonne. Such economic incentives mean grain is often stored for long periods, prior to processing. During this time, grain quality and safety may deteriorate, without appropriate intervention.

Good storage practice minimises risk throughout the supply chain and safeguards food safety for consumers. Critically, effective grain storage helps to minimise loss of premiums, through claims and rejections.

Since the first edition (1999), the Grain storage guide has become a key reference for most assurance schemes. The original edition was endorsed by, among others, AIC, NFU, UKFM and MAGB. The fourth edition (2021) makes the content easier to navigate and understand.

The guide introduces the Hazard Analysis and Critical Control Point (HACCP) system – a legal requirement for all food and feed businesses after primary production, including central grain storage operations. Although HACCP is not required for on-farm crop production activities, including grain storage, this guide is based on its principles. It covers the main hazards/risks to consider during grain storage – from intake to dispatch – and how to prevent/reduce them.

ahdb.org.uk/grain-storage

Keep control of your grain quality

Follow best sampling practice to capture the quality and condition of grain before it leaves your farm.

ahdb.org.uk/grain-sampling

How to identify, evaluate and control hazards (HACCP)

HACCP (Hazard Analysis and Critical Control Point) is a risk-based approach that identifies, evaluates and controls hazards significant for food and feed safety. It helps meet marketplace demands and expectations for safe food and feed.

This guide uses tables to summarise the main hazards and the risk of them occurring. The tables also list preventative, monitoring and corrective actions. Each table relates to a key step in the grain storage process – store preparation (Table 1), initial in-store phase (Table 3), longer-term storage (Table 5) and dispatch (Table 6).

For further information on the use of HACCP in grain stores, visit: **ahdb.org.uk/grain-storage**

HACCP terms used in this guide

Hazard

A biological (e.g. insects), chemical (e.g. pesticide residues) or physical (e.g. glass) agent in food or feed with the potential to cause an adverse health effect.

Hazard analysis

Collecting and evaluating information on the presence of hazards to decide which should be addressed in a HACCP plan.

Preventative measure

Any action or activity used to prevent or eliminate a food safety hazard or reduce it to an acceptable level (also referred to as a ‘control measure’).

Monitoring procedure

A planned sequence of observations or measurements of preventative measures. The records of monitoring provide evidence that the control is effective (also referred to as ‘checking procedures’).

Corrective action

Any action taken when monitoring results indicate a loss of control or trend towards loss of control and, hence, increased risk. The corrective action should include consideration of how to regain control and what to do with potentially unsafe products.

Risk

The significance of hazards is determined by quantifying risk, based on the likelihood of it occurring and the severity of the hazard (in the absence of preventative control measures). In this guide, each hazard score has been converted into a ‘high-risk’ (***), ‘medium-risk’ (**) or ‘low-risk’ (*) rating. A high-risk rating represents a significant food safety hazard and critical control point (CCP).

Critical control point (CCP)

A process step at which control should be applied to prevent or eliminate a food safety hazard or reduce it to an acceptable level. If the controls fail at this point, food safety risk is increased.

Biological, physical and chemical hazards

Biological hazards

In addition to the ochratoxin A (OTA)-producing fungus *Penicillium verrucosum* (see Page 6), biological hazards include pathogenic microorganisms, such as some bacteria (e.g. *Escherichia coli* and salmonella). These may cause infection or food poisoning in consumers. Grain contamination may originate from people, equipment or the store fabric/environment. The latter source may be associated with pest presence or previous store uses, including the housing of livestock.

Chemical hazards

Residues of chemical substances may render the product unacceptable or illegal, where statutory maximum residue levels (MRLs) or permissible levels have been exceeded. Substances include residues of plant protection products, mineral oils, polycyclic aromatic hydrocarbons (PAHs) and cleaning agents.

Physical hazards

Foreign bodies may contaminate grain and cause harm to the consumer or make the grain unacceptable to the customer. Such bodies include glass, metal (e.g. nuts and bolts), stones, brick and concrete, wood, animal contaminants (e.g. rodent or bird faeces), storage pests, shotgun cartridges, lead and clay pigeons. Foreign materials (allergens) may contaminate grain from products stored previously or nearby and cause an allergic reaction in susceptible consumers. Examples include soybeans, nuts and peanuts.

Identification of hazards

To identify defects and impurities in stored grain, access our illustrated guidance via **ahdb.org.uk/grain-storage**

Management of temporary stores

Grain may need to be stored temporarily, prior to drying and moving to longer-term stores. However, the storage of all grain should be in a manner that protects against contamination and does not compromise its quality. As a result, the best-practice measures outlined in this guide apply for temporary stores.

If storing grain temporarily:

- Measure moisture content (MC) as soon as possible
- Identify grain batches at or above 18% MC and prioritise it for grain drying
- Use the AHDB Safe storage time calculator to prioritise grain entry to dryers/longer-term storage
- Consider cooling grain* to 15°C to prolong safe storage time before drying
- Be aware of any restrictions (e.g. with assurance schemes) on temporary storage
- Generally, temporary stores may only be used until 31 October (unless a temporary derogation is in place)

*To cool grain, consider the use of grain stirrers or ambient air and temporary ducts/pedestals or, for small bulks, a cooling spear.

Safe grain storage calculator

The AHDB Safe storage time calculator uses information entered on the moisture and temperature levels for stored grain to assess the risks from mould and mycotoxin development, loss of germination and the potential risk of attack by insects and mites. The times indicated by the calculator commence immediately after harvest and determine the safe storage time for batches or bulks of grain.

Holding grain outside

The Red Tractor combinable crops standards state that: “the holding of grain is only allowed outside of a building in exceptional circumstances and for a maximum of five days, unless a derogation has been sought.”

A grain moisture meter

The main causes of grain spoilage

The main causes of spoilage in stored grain are fungi, insects and mites. Some insects and mites are also able to carry fungal spores associated with the storage mycotoxin ochratoxin A (OTA). However, the direct physical presence of storage pests may also make the grain unacceptable to the customer.

Fungi and mycotoxins

Storage fungi can grow above around 14.5% and 7.5–8% moisture content (MC) on cereal grain and oilseed rape seed, respectively. The activity of each fungal group depends on a combination of moisture content and temperature (Figure 1).

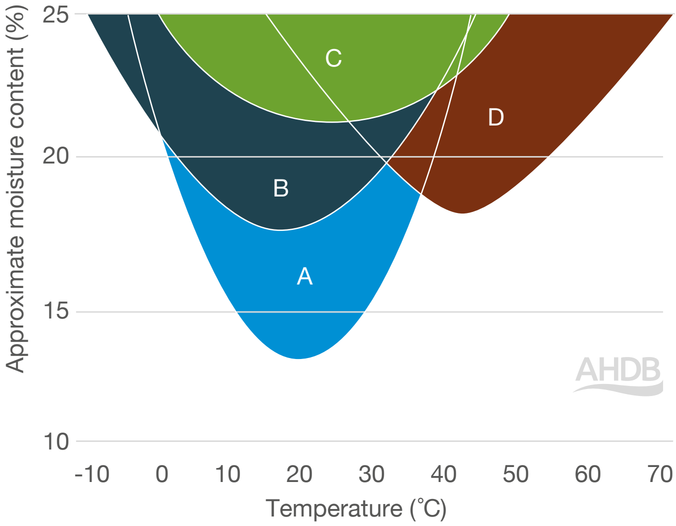


Figure 1. Activity of four fungal groups at various temperatures and moisture contents. A – ***Aspergillus*** **species, which may result in slow heating and damage germination. B –** ***Penicillium*** **species, including those that produce mycotoxins. C – Advanced decay/field fungi, such as** ***Fusarium*** **species and heating organisms. Category C includes potentially pathogenic** ***Absidia*** **species that cause, for instance, farmer's lung. D – Thermophilic fungi, which thrive at very high temperatures, such as those that occur in compost bins**

The main fungus in UK stored grain is *Penicillium verrucosum*. This fungus is active at a relatively wide range of temperatures. When moisture content is at or above 18%, it can produce the mycotoxin ochratoxin A (OTA). EU regulations set permissible levels for OTA at 5 parts per billion (ppb) for cereals at intake, for human consumption. Where grain is stored above 18% MC, these levels can be exceeded in two weeks, if the temperature is sufficiently high. The principal method by which storage fungi can be controlled is through drying and cooling.

Warning

Do not sniff mouldy grain – spores can cause farmer's lung.

Mycotoxins formed before harvest (e.g. by *Fusarium* species) are stable. Although likely to remain during storage, they do not increase. For more information, visit: **ahdb.org.uk/mycotoxins**

Insects and mites

There are three types of insect/mite associated with grain stores – grain-damaging species (primary pests), mould or hygiene-related species (secondary pests) and non-damaging or stray species.

Insects

Stored product insects are specialised for the grain storage environment. They can breed at relatively low temperatures and moisture contents. Even a single insect in a 1 kg grain sample may represent a potentially serious infestation. In general, cereals are more susceptible to insect attack than oilseed rape.

Primary storage pests can survive on grain residues from the previous harvest and will infest new grain as it is placed into the store. As a result, good store hygiene helps reduce insect presence and infestation problems.

Common primary species (Figure 2) are the grain weevil (*Sitophilus granarius*), saw-toothed grain beetle (*Oryzaephilus surinamensis*) and the rust-red grain beetle (*Cryptolestes ferrugineus*).

Figure 2. Common primary insect pests in UK grain stores. Top to bottom: Grain weevil, saw-toothed grain beetle and the rust-red grain beetle

Weevils breed at relatively low temperatures. Grain weevils develop inside the grain, making early detection difficult. As it feeds, the larva hollows out the inside of the grain. When left unmanaged, this can cause 'hotspots', where activity of the last larval stage raises grain temperature locally. As it damages grain (including when it exits the grain as an adult), it makes it easier for other pests to enter. Further temperature increases encourage rust-red grain beetles.

Secondary insect pests, such as the foreign grain beetle, spider beetles and booklice, only damage poorly conditioned grain and are primarily fungus feeders.

Mites

At least twelve mite species infest UK stored grain. The most common are *Acarus, Tyrophagus* and *Lepidoglyphus* species. However, species identification is a task for a specialist.

Storage mites are small (<0.5 mm long) and just visible to the naked eye (Figure 3), seen as white specks or pink dust moving on the grain surface or in sievings. They may accumulate in traps at the grain bulk's surface or in bait bags, mite traps and floor traps in empty stores.

Figure 3. Mite risk increases in stored grain as moisture content increases. This picture shows flour mites (*Acarus silo*)

Mites breed rapidly under favourable conditions (Figure 4). However, they are prone to water loss and die at low relative humidity (rh). Most species do not breed below 65% rh. Numbers at the surface may decline naturally, if the surface moisture content falls below 65% rh in the spring.

Mites can cause direct damage to the grain by eating the germ or hollowing out oilseeds and may also cause taint. They also cause allergic reactions, although only usually associated with large populations of mites. Predatory mites may also be present, especially where there are large populations of storage mites.

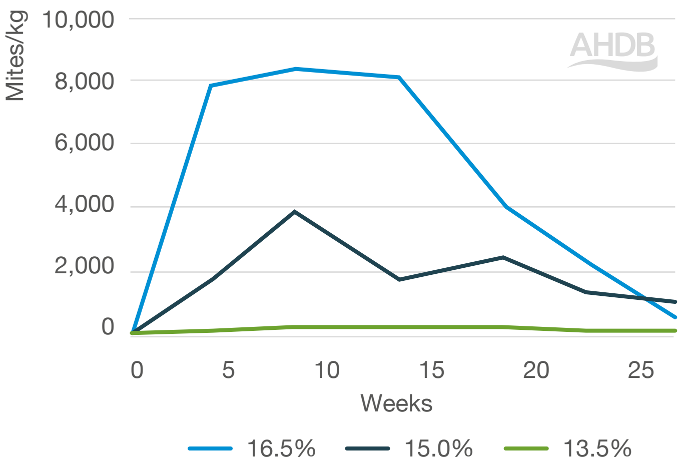


Figure 4. Cosmopolitan food mites (*Lepidoglyphus destructor*) at the grain surface (bins of malting barley) at three moisture contents

How to identify insects and mites

Our website includes images of over 50 insect and mite species that may occur in grain stores. It covers the primary insect pests, as well as secondary pests, mites, moths and booklice. Correct identification is important to determine the appropriate management response.

ahdb.org.uk/grain-storage

Store preparation

Thorough store preparation and hygiene help to eliminate sources of contamination from storage fungi, insects and mites. This is essential, irrespective of whether grain is held for a temporary or longer period.

Insects and mites are most likely to be introduced from the store structure and equipment. Even small quantities of grain provide a food source, allowing pest problems to build. It is also essential to manage rodent populations.

However, cleaning alone does not eliminate all pests in empty stores, nor will pesticide treatment. The key to safe storage of grain is to use an integrated pest management (IPM) approach to prevent, monitor/detect and control any issues.

Pre-harvest store preparation

- Inspect/repair areas of potential water ingress (e.g. external fans, guttering and roofs)
- Check that the store is proofed against rodent and bird entry
- Ensure there is adequate space above grain for ventilation
- Test/maintain equipment
- Use shatter-resistant bulbs and fit shatter-proof light covers
- Know the storage history (e.g. livestock housing or potato storage)
- Clean the store and equipment thoroughly
- Set up insect traps and rodent bait boxes

Use an industrial vacuum cleaner to remove debris, including from harder-to-reach areas. Conveyor systems may harbour relatively large amounts of the storage fungus *Penicillium verrucosum*. Ensure rubbish, including vacuum-cleaner contents, is removed and disposed of well away from the store.

Use appropriate food-approved disinfectant/sanitiser and leave to dry before storing grain. The permitted cleaning products and previous store uses may depend on supply chain restrictions – check for approval and suitability before use.

Insect traps

Place insect traps, such as pitfall cone traps, floor traps and bait bags, in corners and at wall/floor junctions every 4–5 metres around the store. Check them weekly. If stored product insects or mites are found, place additional traps to pinpoint the source of the infestation. Further hygiene measures may help eliminate the source.

Rodent management

The presence of rats and mice, in and around grain stores, may result in losses to grain and grain quality, and damage to buildings and machinery. As part of a rodent-management plan, always:

- Use secure, commercially approved bait boxes
- Have a sufficient number of baiting points
- Note the locations of bait boxes
- Record bait quantities
- Place bait boxes outside the store
- Prevent bait contamination of grain
- Minimise exposure to non-target animals
- Collect and dispose of dead rodents
- Inspect regularly
- Remove bait at the end of the treatment

For information on rodent-bait use, visit the Campaign for Responsible Rodenticide Use (CRRU) website: **thinkwildlife.org**

Table 1. Store preparation: hazards and management

Key hazards	Risk score	Management		
		Preventative measures	Monitoring procedures	Corrective actions
Fungi with potential to cause mycotoxins	**	Clean equipment and store	Inspect cleanliness	Targeted cleaning
Insects and mites	**	Clean equipment and store	Use traps	Apply pesticide at recommended rate
Pesticide residues	*	Use approved products in recommended manner	Check records of pesticide application	Review applications and practices
Rodents and rodent faeces	*	Clean store, remove (where possible) potential places of shelter and prevent entry	Check for rodent presence	Use rodenticides in recommended manner; targeted cleaning and proofing
Birds and bird faeces	*	Clean store and prevent entry	Check for bird presence	Targeted cleaning and proofing
Glass	*	Glass control procedures	Check for compliance with procedures	Remove and replace or protect glass

HACCP risk rating: *** high risk, ** medium risk, * low risk

In-store moisture management

A combination of high moisture content (MC) and high temperature results in a greater risk of fungal development and mycotoxin formation. The grain surface also absorbs moisture in winter. Even when bulk MC is low, increases at the surface may result in high mite populations.

At harvest, use appropriate and accurate – annually calibrated – equipment to assess moisture content and temperature of grain. In store, manage moisture and temperature to meet targets.

Note: Grain contracts specify moisture content, which, if not met, will result in penalties.

How to measure moisture

Direct ‘oven method’ (most accurate)

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. Grinding and temperature control are both critical.

Indirect ‘moisture meter’ method

Meters measure moisture content indirectly, using grain resistance or capacitance. AHDB research shows that grain (wheat and barley) with moisture contents at or above 18% tend to under-read by as much as 1%, with greater variability in freshly harvested grain. At around 15% MC, meters were usually within ±0.5% of the oven test. Repeat testing of the same sample gave meter readings within ±0.3%.

Laboratory and on-farm tests gave equally accurate and consistent results for all meters tested – both capacitance and resistance.

Accuracy and consistency

Accuracy

A measurement of how closely a moisture meter reading matches the oven test. Accuracy is important to avoid spoilage or mycotoxin formation.

Consistency

Achieved when multiple tests of the same sample produce similar results. Meter maintenance and best practice help ensure consistent readings.

A grain moisture meter

Accuracy of consistency of moisture meters*

Use equipment as the manufacturer intended

Ensure calibration and maintenance is undertaken each year (ideally, by manufacturer). Always follow usage instructions. Ensure grain moisture is within the range of meter/probe. Poor operator practice may cause moisture meter errors of up to ±1%.

Use representative samples

Sample variability has the greatest influence on consistency (discrepancies of up to ±1%). Test samples that are representative of the bulk and free of contaminants (e.g. soil, screenings).

Determine moisture content

Keep samples in a watertight container, with minimum free air space, at an even air temperature. Mix each sample thoroughly before testing. However, be aware that moisture content variability potentially increases in freshly harvested grain, even within a well-mixed sample.

Account for temperature gradients

Allow sufficient time for meter/probe and grain temperatures to equilibrate. Errors of up to ±1% may occur when sample and meter temperatures differ by 15°C.

Sample preparation (grinding) for resistance meters

Ensure that grinder is properly maintained – readings may be 1% lower with a worn grinder. Coarse grinding is sufficient and further grinding results in less accuracy. Compress ground sample as specified.

Use one calibration for UK wheat only

No differences were found using four meters to compare 20 wheat varieties – 13 with hard and 7 with soft endosperm. Where a meter had two calibrations for wheat, the soft calibration was the most accurate.

Capacitance meters

Use meters on level surfaces. Allow for a 0.4% moisture content increase (compared with the same samples reanalysed a week later) when analysing freshly dried grain with a capacitance meter.

Moisture probes

Use probes to rapidly monitor the moisture content of grain within a bulk, but not in place of meters to assess moisture content of samples. Although not as accurate as meters in tests, probes gave consistent and reliable results. However, depth of insertion affected both types – low readings resulted at less than 0.5 m depth. Both types of probe – resistance and capacitance – were equally accurate, but resistance probes only gave a steady reading once probe and grain temperatures had stabilised after a minute or more.

Allow a safety margin

It is prudent to treat meter readings conservatively. Errors are frequently ±0.5% and can be greater in very wet, very dry or freshly harvested grain. Farmers who allow a 0.5% safety margin are far less likely to have claims for excess moisture.

*This guidance is based on an AHDB-funded project and practical experience.

Moisture targets for cereals

- Food safety risk increases above 14.5% MC in cereals
- If grain is stored below 13% MC, moisture uptake is considerably limited, effectively preventing mites breeding
- Dry grain with a high moisture content (at or above 18% MC) immediately
- Commercial grain is commonly traded at moisture contents of 15% and above

The safe time to achieve the recommended moisture content will depend on the grain temperature. The impact of any particular temperature and moisture content combination can be assessed using the AHDB safe storage time calculator.

From a safety perspective, it is always better to store grain at a lower temperature. This is because the grain exchanges water with the surrounding air and, in enclosed spaces, this continues until a balance (the equilibrium relative humidity – ERH) is reached. As the temperature decreases, so does the ERH. 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%. Mould growth and mite reproduction stop below 65% ERH (Table 2).

Table 2. The relationship between grain (wheat) moisture content, temperature and equilibrium relative humidity (ERH)

Moisture content	Grain temperature		
	5°C	15°C	25°C
16.5%	68% ERH	74% ERH	76% ERH
15.5%	62% ERH	69% ERH	71% ERH
14.5%	56% ERH	64% ERH	66% ERH
13.5%	49% ERH	58% ERH	60% ERH

Note: Mould growth and mite reproduction stop below 65% ERH (green squares).

Moisture targets for oilseed rape

Oilseed rape and cereals have different relationships between moisture content and equilibrium relative humidity (Figure 5). Oilseed rape has lower moisture content targets.

- For prolonged, stable storage, dry oilseed rape to 7.5–8% moisture content, as soon as possible
- Do not dry oilseed rape below 6% – the lowest acceptable moisture content

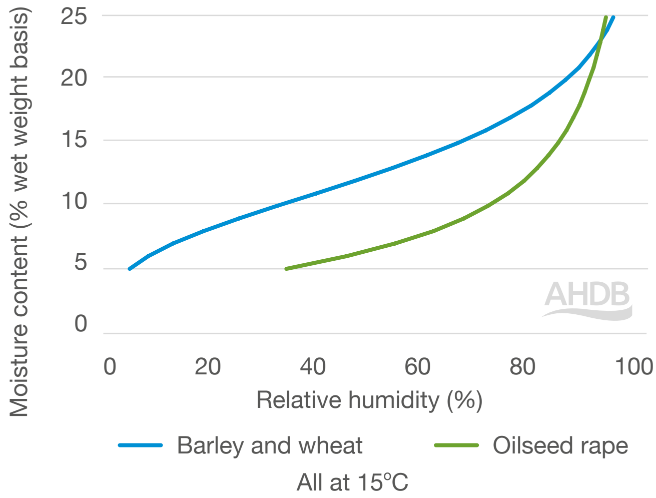


Figure 5. The relationship between relative humidity and grain moisture content in barley, wheat and oilseed rape

In-store drying

There are two basic methods of grain drying – high-temperature and near-ambient air drying.

High-temperature drying

- Air heated to at least 40°C
- Heat generated from oil or gas
- Uses batch or continuous dryers
- Generally, grain is moved to limit overdrying and heat damage

Capital costs: High

Speed: Fast – grain is in a shallow layer with high airflow

Management skills: Follow manufacturer's instructions

Weather: Independent of weather conditions

Temperatures: Max of 65°C at 20% MC, reducing by 1°C for every 1% increase in initial MC

For feed grain: Max of 120°C for 1 hour or 100°C for 3 hours

Spoilage risks: Low risk of slow drying. Risk of overheated grain. Some risk of overdrying.

Notes

- Maltsters, millers and seed producers require that grain temperatures do not exceed 50°C
- Do not leave grain in the dryer for too long
- Ensure adequate airflow
- After drying, cool grain to prevent breeding of insects and mites
- Rapeseed becomes brittle at low MC, so overdrying can be a problem
- Free-fatty-acid content increases rapidly in broken seed and may cause oil degradation after crushing

Hydrocarbon contamination

If a direct drying system uses an oil-fired energy source, manage the hydrocarbon contamination risks. Ensure that the fuel meets commercial ISDN/ISO standards and that there is efficient combustion (by setting air:fuel ratios to manufacturer's recommendations). Provide adequate ventilation to prevent the recirculation of burner exhaust gases into the intake cowling to reduce taint risk. An additional risk is the development of polycyclic aromatic hydrocarbons (PAHs), if combustion is incomplete.

Grain moisture calculator

Use the AHDB grain moisture calculator to estimate the weight loss associated with drying 1 tonne of cereals. Simply enter the 'initial moisture' and 'final moisture' values from representative samples of grain. Alternatively, use the look-up table for a range of specific values.

ahdb.org.uk/grain-storage

Near-ambient air drying

- Used for bulk grain stored in bins or on floor
- Air, up to 5°C warmer than the grain, is blown through the bulk

Capital costs: Low

Speed: Slow – typically, 10 days with recommended airflows of 180 m^3/hr/tonne or 6,357 ft^3/hr/tonne

Management skills: Need to respond to moisture content and weather conditions

Weather: Wet weather slows drying

Moisture content: If initial moisture content is high, drying capacity is reduced

Spoilage risks: Higher risk of slow drying. Low risk of overheated grain. Some risk of overdrying.

Notes

- Drying occurs in a layer that develops at the air intake, before moving through the bulk – grain ahead of the drying zone remains wet and may also be warm, increasing the risk of spoilage
- Individual seeds present different resistances to airflow, so bed depth is a critical factor – check airflow is adequate by taking measurements at several points using an anemometer

Grain stirrers

In most years, on-floor drying can be effective and economical. However, in some seasons, it will incur considerable costs and may not achieve good enough results. Grain stirrers can be used to mix the grain vertically, resulting in a mix of dry and undried layers. An AHDB-funded project demonstrated that stirring reduces the length of time that the upper layers of the grain spend at the initial moisture content – providing there are sufficient stirring augers to be effective for the whole bed.

Grain depth

Spoilage risk increases as grain depth exceeds a fan's design maximum – as airflow reduces, it slows the advance of the drying zone. 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%.

Table 3. Initial in-store hazards and management

Key hazards	Risk score	Management		
		Preventative measures	Monitoring procedure	Corrective action
Production of ochratoxin A	*** Critical control point	Commence drying above 18% MC Immediately, dry grain to 14.5% MC	Measure temperature and moisture content	Investigate changes in moisture content; review practices and grain condition
Introduction of fungi with potential to cause mycotoxins	**	Clean area and equipment	Inspect for mouldy grains	Dry grain to 14.5% MC; commence drying of grain above 18% MC immediately
Introduction of insects and mites from store fabric	**	Clean area and equipment	Use traps	Consider need for pesticide treatment
Growth and development of insects and mites	*	Cool and dry to recommended levels	Use traps; measure temperature and moisture content	Investigate significant changes in moisture content; review practices and grain condition
Pesticides exceed maximum residue levels due to incorrect admixture	**	Use only approved products in line with manufacturer's guidance; check condition and calibration of spray equipment	Check records of pesticide application	Review applications and practices
Introduction of hydrocarbons from direct-fired drying systems	**	Use appropriate grade oil; ensure efficient combustion and adequate ventilation	Check before use	Remedy defects
Introduction of rodent faeces during grain cleaning	*	Clean store and proof to prevent ingress of rodents	Check for presence	Check proofing measures; consider control options

HACCP risk rating: *** high risk, ** medium risk, * low risk

In-store cooling

Grain is a good insulator and loses heat slowly. Cooling should commence as soon as the grain comes into store. This permits grain to be stored at higher moisture contents and effectively increases the safe storage time. It also evens out or equalises temperature gradients and reduces moisture translocation.

Grain storage temperatures

Above 40°C: Most insects die within a day

33–25°C: Most insects breed rapidly

25–15°C: Mycotoxin formation is most likely

15–12°C: Most insect species stop breeding, although grain weevils may still reproduce (although slowly)

5°C: In moist grain, mites and fungi may still increase (although slowly)

Below 5°C: Insects stop feeding and mites stop increasing

Grain cooling targets

Use low-volume aeration (10 m^3/hour/tonne or 6 ft^3/min/tonne) to cool grain as soon as ducts are covered.

- Within 2 weeks of harvest – cool grain to below 15°C to reduce insect activity (e.g. prevent saw-toothed grain beetles completing their life cycle)
- Within 3–4 months of harvest – cool to below 12°C to stop insect activity (e.g. prevent grain weevils completing their life cycle)
- By the end of December – cool to below 5°C (read more in the section below) to help kill adult insects and prevent mites increasing

Malting barley cooling/moisture targets and germination

A natural condition, dormancy prevents grain sprouting in the ear.

Malting barley is purchased based on agerminative capacity test (ideally, viability is 100%).

Germination should be tested before storage, after three months' storage and/or prior to delivery.

Usually, stored barley grain is not cooled to below 10°C, as it can increase the risk of inducing secondary dormancy.

Ideally, for long-term storage, malting barley is dried to about 13% MC. Germination capacity declines rapidly at higher moisture contents and temperature.

Grain bed depth

If the depth of grain is too great, cooling success may be reduced. At greater depths, distance between ducts needs to be reduced (Table 4).

Table 4. Grain depth and duct spacing

Grain depth (m)	2.0	3.0	4.0	5.0	6.0	7.0	8.0
Duct centres (m)	7.6	6.3	5.5	5.0	4.4	4.0	3.7

Data typical of commercial systems that use a 250 mm diameter by 920 mm high perforated metal duct served by a fan working at 70 mm WG designed to cool about 95 tonnes of grain in 100 hours of ventilation. Follow supplier's recommendations for specific products.

Oilseed rape has a much higher resistance to airflow than cereals. If using an aeration system designed for conventional cereal storage, reduce the bed depth by 50–70%.

Differential controls

A differential controller/thermostat switches on the cooling fan when the ambient air temperature is lower than the grain temperature. Compared with manual control, this reduces the number of fan hours required to reach the target temperature and energy costs.

- Place the ambient sensor close to the fan inlet, but not in a position where it is affected by heat generated from the fan
- Place the probe in the region of the grain bulk that is the slowest to cool, but not too close to the surface (to avoid tracking of the ambient temperature)

The use of differential thermostats on cooling fans at a differential setting of 4–6°C provides the most rapid, cost-effective and carbon-efficient cooling. If blowing with cooler air, using a differential thermostat (4–6°C difference), it is far less likely to dampen grain. For grain to become damp from blowing, you need a combination of:

- Excessive aeration rates
- Condensation around ducts (especially 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 front may extend to one-third of grain depth.

Vertical aeration

Vertical aeration systems can be just as effective as horizontal systems. The advantages of vertical systems are that the capital costs are lower and the risk of damaging ducts during unloading in flat stores is reduced. Spacing of ducts will depend on grain depth. However, placing ducts 4–8 m apart is often suitable for an average flat store of grain. Blowing and sucking systems are available, which affect the progress of cooling through the grain (Figure 6).

Blowing air

- Improves air distribution – cools 20% more grain than sucking
- 'Problems' rise to the surface
- Fan heating reduces relative humidity of blown air
- Warm, damp air is flushed from the building
- Cooling can start as soon as ducts are covered

Sucking air

- May increase dampening at the grain surface during winter and this dampening front may extend to one-third of the grain depth
- Is useful if condensation on the inside of roofs is a problem (although good ventilation can overcome this) or there is a risk of water entering aeration ducts
- Use if grain depth is so great that excessive temperature rise would occur with blowing

Airflow

- Fans need sufficient pressure to overcome resistance, due to the crop, the depth and the duct characteristics
- Ducts need to be of sufficient diameter and have sufficient perforated area to minimise resistance
- Measure using an anemometer in a measuring duct, of appropriate diameter and length, placed in front of or after the fan
- A floatmeter should not be used to measure airflow for low-volume aeration

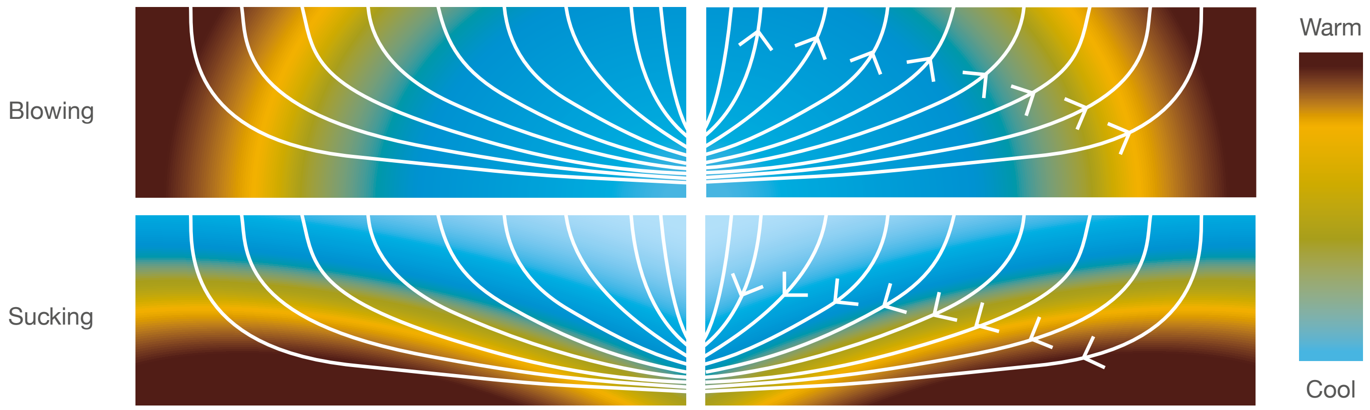


Figure 6. Progress of grain cooling with blowing and sucking systems after 100 hours of ventilation in a bed 3 m deep (arrows indicate airflow paths)

In-store monitoring

During longer-term storage, frequent monitoring for the presence of insects and mites is essential. Regular measurement of temperature and moisture is also important, as increases may point to emerging pest problems.

Temperature monitoring

- Monitor every few days until target reached, then weekly
- Always record at the same location
- Take measurements where cooling takes longest – furthest from the fan in blowing systems, usually 0.5 m beneath the surface and centrally between ducts
- Use a calibrated grain temperature probe (thermocouples or thermistors)

Increased temperatures may indicate presence of fungi, sprouting or development of grain weevils.

Moisture monitoring

- Monitor at several locations (same each time)
- During winter, record at least monthly
- Allow a safety margin (see 'In-store moisture management' section for details)

If moisture content increases in a localised area of 2% or more in a week, identify the cause – e.g. condensation, leaks, hotspots or insects – and take necessary action.

Pests and mite monitoring

Due to complex environmental conditions and insect behaviour, a simple relationship between actual insect numbers and the quantities caught in traps cannot be accurately determined. However, traps do provide an indication of population trends. Traps are also up to ten times more effective than grain sampling at detecting low numbers of pests.

Some traps are designed for use in the store, others for use within the grain bulk. Place traps 4–5 m apart. Position traps within the grain bulk on the surface and around 5–10 cm below the surface (e.g. a combination of probe and pitfall cone traps in pairs) to target different insect and mite species with different behaviours. Ensure that insect bait traps do not contain allergens (e.g. nuts).

Monitor weekly, until grain reaches and stays at 5°C, then monitor monthly. Additionally, check for storage mites in the surface layer of the grain.

Traps should be accounted for each time they are examined and a permanent record of the contents kept. Record-keeping, either electronically or on paper, will illustrate due diligence and enable changes in grain condition to be readily identified. This can provide an early warning of potential problems.

If pests are detected, increase the number of traps to determine extent of infestation and consider the need for treatment.

How to identify insect and mites

Our website includes images of over 50 insect and mite species that may occur in grain stores. It covers the primary insect pests, as well as secondary pests (Figure 7), mites, moths and booklice. Correct identification is important to determine the appropriate management response.

ahdb.org.uk/grain-storage

Figure 7. Increasingly common in the UK, the foreign grain beetle is highly mobile and a common cause of rejection

In-store pest and mite control

If stored product pests are found, identify the cause and consider the need for appropriate treatment. Pest and mite control options include residual insecticides, fumigants and physical desiccants.

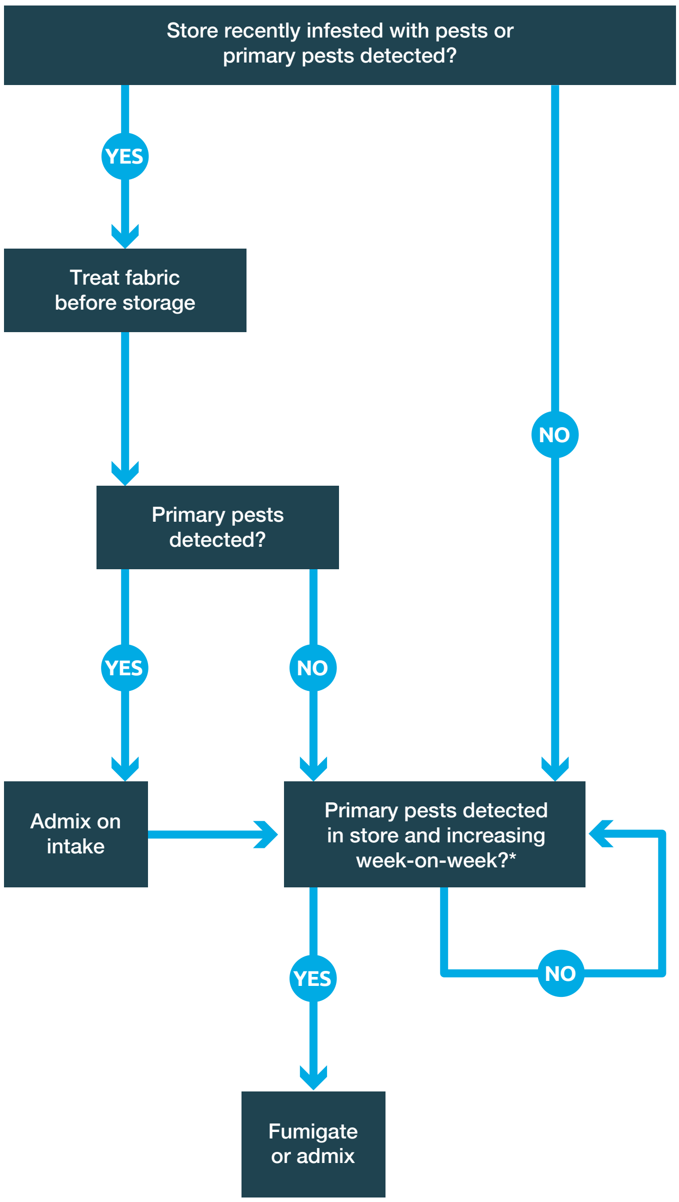
If pests are persistent or widespread, consider applying an approved pesticide to the fabric of the building at the manufacturer's recommended rate.

The intended use and market of the grain may determine the products that can be applied. Chemical treatment to prevent fungal growth can only be used on grain for animal feed.

Ensure that the correct rate is applied with serviced and calibrated application equipment. This will also minimise the risk of exceeding maximum residue limits and pesticide resistance. Details of all treatments should be documented.

The efficacy of any treatment can be monitored by checking and replacing insect/mite traps two days after treatment.

Monitor at every step



*In store, cool grain rapidly

Information on plant protection products approved for UK use (structural and grain treatments) is available from the Chemicals Regulation Division (CRD) website: **pesticides.gov.uk**

Residual insecticides/admixtures

Application of a residual insecticide (by trained personnel):

- Provides protection over a prolonged period, dependent on the type of surface and the temperature
- May take time to control an existing infestation
- May take a relatively long time to achieve control at lower temperatures (depending on the active ingredient)

If a residual pesticide treatment is used, it must have approved usage for admixture to the grain and be applied at the manufacturer's recommended rate. Currently, only organophosphorus (OP) compounds are approved for admixture to grain. In cereals, mites can be discouraged by accurate application to the bulk of a liquid OP at recommended rates. Dust formulations are no longer available. Treatment of infestations is more difficult, as they are not particularly susceptible to OPs.

Fumigants

- No lasting activity but penetrate and disinfect static bulks
- Control all stages of infestation in one treatment, if correctly applied

Diatomaceous earth (DE)

- A physical control (siliceous dust) that desiccates insects and mites (limiting population growth)
- Not accepted by some supply chains due to health and safety concerns (dust) and the inability to remove it from the grain, which can affect machinery
- If the entire bulk is treated, DE may limit grain flow. As a result, it can only be incorporated at effective application rates to the grain surface
- Only gives longer-term control when combined with an effective drying and cooling regime
- To prevent mites occurring at the surface of grain, rake DE into the top 0.3 m at 200 g/m^2 (1 g/kg). To deal with surface infestations, treat with 600 g/m^2 (3 g/kg)
- Control of the least susceptible pest, grain weevils, could take several weeks

Insecticide resistance

Some pest insects and mites have developed resistance to some currently approved pesticides. Resistance management includes ensuring correct application at the manufacturer's recommended rate and consideration of the use of a product containing an active substance with a different mode of action (MOA) to that used previously. For further information, visit the Insecticide Resistance Action Group (IRAG) web page: **ahdb.org.uk/irag**

Personal protective equipment (PPE)

When using chemical treatments, take appropriate safety measures, including the use of adequate personal protective equipment (PPE). PPE is also essential when stores are cleaned, loaded and unloaded (Figure 8).

Figure 8. Grain dust is a respiratory sensitiser. Personal protective equipment (PPE) includes protective clothing and respiratory protective equipment (RPE)

Table 5. Longer-term storage: hazards and management

Key hazards	Risk score	Management		
		Preventative measures	Monitoring procedure	Corrective action
Production of ochratoxin A	*** Critical control point	Store grain below 14.5% MC and 5°C, except malting barley, which should not be stored below 10°C	Check temperature and moisture content regularly	Investigate any significant changes; review practices and grain condition
Development of insect and mite populations	*** Critical control point	Store grain below 14.5% MC and 5°C, except malting barley, which should not be stored below 10°C; store oilseed at 7.5–8% MC and <5°C	Position traps and check traps correctly; check temperature and moisture content regularly	Investigate source of infestation and any significant changes in MC or temperature; review grain condition and practices; consider need for treatment
Introduction of pesticide residues	**	Use only approved products and conform to manufacturer's guide for use; check condition and calibration of spray equipment	Check records of pesticide application	Review applications and practices
Introduction of bird and rodent faeces	*	Keep store clean and proof to prevent entry	Check for bird and rodent presence	Check proofing measures; consider control options
Introduction of glass	*	Glass control procedures	Check for compliance with procedures	Remove and replace or protect

HACCP risk rating: *** high risk, ** medium risk, * low risk

Dispatch

Throughout the dispatch and transportation process, it is important that the premises, equipment and transportation vehicles remain as clean as possible.

Grain residues in vehicles can be a source of stored product insects and mites. Therefore, take care to remove deposits of grain in the vehicle, as soon as possible after transportation.

Table 6. Dispatch: hazards and management

Key hazards	Risk score	Management		
		Preventative measures	Monitoring procedure	Corrective action
Introduction of storage fungi	*	Clean outloading equipment and transport	Visually inspect	Targeted cleaning
Introduction of insect and mite populations	*	Clean outloading equipment and transport	Visually inspect	Targeted cleaning

HACCP risk rating: *** high risk, ** medium risk, * low risk

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