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GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

BARLEY

SECTION 13

STORAGE

HOW TO STORE BARLEY ON-FARM | STORAGE OPTION | AERATION DURING STORAGE | HYGIENE | GRAIN PROTECTANTS AND FUMIGANTS | MONITORING BARLEY

Storage

Successful on-farm storage depends on a range of factors. These include storage and handling equipment, capital costs and management used to maintain grain quality, and the control of insects and mould.

Current deregulation of grain markets is now creating a need for more long-term on-farm storage of grain which will eventually enter commercial trade. This allows growers to exploit market opportunities and to apply grain management procedures to maximise crop income. On-farm storage of commercial grain requires large, cheap-per-tonne stores and improved grain management, including pest control. [1]

Established strategies

The best insurance a grower can have is to place extra emphasis on the management of their grain storage facilities. Key strategies include:

- High standard of hygiene for storages and grain handling equipment minimising insect pest breeding sites
- Monthly checks of grain in storage, including planting seed grain, sieving for insects and checking quality
- Aeration fans fitted to storages, operated by an automatic controller
- Grain temperatures–checked and achieving 20–23°C in summer and less than 15°C in winter
- Fumigations, when required, are carried out in sealable silos. These silos are pressure tested at least once a year
- Storage record keeping–a simple system to record details such as grain variety, moisture content, treatments, inspections dates, and data for insects and grain temperature [2]

13.1 How to store barley on-farm

13.1.1 Malt barley

Keeping malting barley alive and respiring is vital for the malting process. Only a live barley grain will trigger the stream of biochemical reactions required to convert barley into malt suitable for brewing. It is important barley growers understand the need to store barley correctly to maintain germinative capacity and vigour, so it can be effectively processed into malt. [3]

Special consideration should be given to storing malt barley. Storage conditions largely determine the rate at which quality parameters of Australian barley varieties change after harvest. Initial kernel condition, temperature, moisture content and storage time are major factors influencing changes in malting quality.

Barley is typically harvested and initially stored at moderate temperatures (25–30°C). Depending on storage conditions, Australian malting barley can take several months to reach optimum malting quality while dormancy and water sensitivity are broken down.

Manipulating storage conditions can provide maltsters with homogeneous barley to malt. Research has identified several options for managing barley dormancy to provide opportunities to malt and export barley earlier, such as the use of agricultural chemicals or application of dry heat.

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1 Stored Grain Information Hub (2016) Select grain stores carefully to control costs. http://storedgrain.com.au/select-grain-stores-carefully-to-control-costs/

2 P Burrill (2013) Grain storage future pest control options and storage systems 2013–2014. GRDC Update Papers, July 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Grain-Storage-Future-pest-control-options-and-storage-systems-2013-2014

3 Barley Australia (2007) Germination a must for malting barley. http://www.seednet.com.au/documents/MEDIA_RELEASE_sausage_bags_June_2007.pdf

GRDC-funded CSIRO research shows understanding and carefully manipulating the storage process, post-harvest dormancy can be removed without compromising barley quality. [4]

Delaying aeration cooling for a short period, or raising the grain temperature using aeration fans during the warmer part of the day followed by rapid cooling after dormancy has been removed, can effectively accelerate the maturation of barley. [5]

Mould

The key element of a successful commercial on-farm grain storage system is safekeeping grain against insect and mould damage. This is particularly important in Australia where wheat and barley are taken into storage at high grain temperatures and where long, hot summers and short, mild winters favour insect development. During recent years, some growers who invested significant capital in on-farm storage have turned away from their investment because of difficulties in maintaining grain from insect attack and moulding.

The best way to protect grain against mould development is to dry it to moisture levels below which mould spores can develop before it is transferred into storage.

If the grain moisture content exceeds certain critical values, the spores of specific fungal species will start developing. These critical moisture values often occur at increments as small as 0.5% and therefore accurate and dependable moisture measurement is important. Moulds develop at a fast rate if grain temperature is high, but the key factor is grain moisture content. Safe moisture content for barley is 12.5% or less. [6]

MORE INFORMATION

GRDC (2013) Economics of on-farm grain storage: A Grains Industry Guide.

GRDC (2015) National grain storage extension project. Ground Cover Issue 119.

13.2 Storage option

Short-term storage options (bunkers, bags and sheds) are suited to cereals, which can be moved without damage and if permitted have protectants applied at time of in-loading. For growers planning to store grains that cannot have protectants applied or are to be stored for more than 3 months, then gas-tight, aeratable silos are the best option. [7]

13.2.1 Silos

According to the Kondinin Group National Agricultural Survey 2011, silos account for 79% of Australia's on-farm grain storage, compared with 12% bunkers and pits, and 9% grain bags.

Aerated silos that can be sealed during fumigation are widely acknowledged as the most effective way to store grain on-farm (Table 1). An Australian standard (AS2628) is now available for sealable silos that manufacturers in Australia can choose to use as a construction standard to ensure reliable fumigation results.

4 CSIRO and Barrett Burston Malting Co. (2003) The effect of storage conditions on post-harvest maturation and maltability of barley. E-Malt, http://www.e-malt.com/statistics/ScientificDigest/BTSbarleyStorage.pdf

5 CSIRO (2011) Stored barley manipulated to brew better beer. CSIRO Food and Agriculture June 2010, Updated October 2011.

6 Stored Grain Information Hub (2016) Select grain stores carefully to control costs. http://storedgrain.com.au/select-grain-stores-carefully-to-control-costs/

7 GRDC (2016) On-farm storage needs careful calculation. Ground Cover Issue 125. https://grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-125-NovemberDecember-2016/On-farm-storage-needs-careful-calculation

Table 1: *Advantages and disadvantages of grain storage options*

Storage type	Advantages	Disadvantages
Gas-tight sealable silo	• Allows phosphine and controlled atmosphere options to control insects • Easily aerated with fans • Fabricated on-site or off-site and transported • Capacity 15–3,000 t • ~25-year service life or more • Simple in-loading and out-loading • Easily administered hygiene (cone base particularly) • Can be used multiple times in a season	• Requires foundation to be constructed • Relatively high initial investment required • Seals must be regularly maintained • Access requires safety equipment and infrastructure • Requires an annual test to check gas-tight sealing
Non-sealed silo	• Easily aerated with fans • 7–10% cheaper than sealed silos • Capacity 15–3,000 t • ~25-year service life, or more • Can be used multiple times in a season	• Requires foundation to be constructed • Silo cannot be used for fumigation—see phosphine label • Insect-control options limited to protectants in eastern states and dryacide in WA • Access requires safety equipment and infrastructure
Grain storage bags	• Low initial cost • Can be laid on a prepared pad in the paddock • Provide harvest logistics support • Can provide segregation options • All ground-operated • Can accommodate high-yielding seasons	• Requires purchase or lease of loader and unloader • Increased risk of damage beyond short-term storage (typically 3 months) • Limited insect-control options, fumigation only possible under specific protocols • Requires regular inspection and maintenance, which needs to be budgeted for • Aeration of grain in bags currently limited to research trials only • Must be fenced off • Prone to attack by mice, birds, foxes, etc. • Limited wet-weather access if stored in paddock • Single-use only • Need to dispose of bag after use
Grain storage sheds	• Can be dual-purpose • 30-year service life, or more • Low cost per stored tonne	• Aeration systems require specific design • Risk of contamination from dual-purpose use • Difficult to seal for fumigation • Vermin control difficult • Limited insect control options without sealing • Difficult to unload

Growers should pressure-test sealable silos once a year to check for damaged seals on openings. Storages must be sealed properly to ensure that high concentrations of phosphine gas are held long enough to give an effective fumigation.

At an industry level, it is in growers' best interests to fumigate only in gas-tight sealable storages to help stem the rise of insect resistance to phosphine. This resistance has come about because of the prevalence of storages that are poorly sealed or unsealed during fumigation. [8]

13.2.2 Bunkers and shed storage

Other grain store types currently available for on-farm use include bunkers and sheds. Included in this category are steel mesh structures lined with plastic sheeting. Large bunkers (20–30 kt) provide cost-effective grain stores but the cost per tonne of storage capacity increases significantly as the bunker size decreases. The need to replace the plastic sheeting every few years to maintain a weatherproof seal significantly increases the capital cost of the structure over time.

Bunkers consisting of plastic sheeting can be beneficial fumigation enclosures for grain safekeeping. The main advantage of bunkers is most of the capital outlay is spread over its period of use. Small sheds, which can be gastight sealed for successful fumigation with phosphine are also available for on-farm grain storage.

These sheds are based on hybrid technology with bolted corrugated steel silos. Shipping containers, which can be bought or rented, can also be used. A 6.15 m container can accommodate about 27 t of grain and can be fitted with a polyethylene liner to improve its gas tightness for fumigation.

Grain handling equipment for on-farm in-loading and out-loading from small bunkers, sheds and shipping containers currently rely on mobile augers, which can be difficult to use. [9]

13.2.3 Grain bags

Due to their short-term storage capacity and suitability for supporting harvest pressure, growers tend to use grain bags primarily for extending existing storage during high-yielding seasons, typically for wheat and barley. Aeration cooling is not yet proven with grain bags.

Cereal grain quality is best preserved when the moisture content is below 12.5%. Storing grain of a higher moisture content in bags not only compromises grain quality but increases the risk of grain swelling and splitting the bag.

Being unable to aerate bags and having a large surface area exposed to heating from the sun means grain remains warm for months after harvest. This can affect seed germination rates and malt barley quality. Storing grain at harvest temperatures of 30°C and above favours high insect reproduction rates, so take extra care with hygiene and monitoring. Bulk grain bags are an effective form of storage when used in the right situations and when they are managed correctly. [10]

13.2.4 Grain storage costs

When making a decision about installing on-farm grain storage facilities, consider the following costs:

- The cost of fixed assets, for example, the capital costs of the storage structure, grain handling equipment and grain safekeeping equipment. Included in this are delivery, construction and installation costs to provide a fully operational facility

8 C Warrick (2011) Fumigating with phosphine, other fumigants and controlled atmospheres: Do it right—do it once: A Grains Industry Guide. GRDC, https://grdc.com.au/__data/assets/pdf_file/0025/206791/fumigating-with-phosphine.pdf.pdf

9 Stored Grain Information Hub (2016) Select grain stores carefully to control costs. http://storedgrain.com.au/select-grain-stores-carefully-to-control-costs/

10 GRDC (2014) Successful storage in grain bags. Fact sheet, July 2014, http://storedgrain.com.au/wp-content/uploads/2014/09/GSFS-6_GrainBags-July14.pdf

MORE INFORMATION

GRDC (2014) Successful storage in grain bags. Fact sheet.

GRDC (2013) Grain storage: Silo buyer's guide. Fact sheet.

GRDC (2012) Performance testing aeration systems. Fact sheet.

GRDC (2011) Fumigating with phosphine, other fumigants and controlled atmospheres.

- The cost of owning the facility, which includes maintenance, depreciation on capital equipment, insurance and opportunity cost of interest on money invested in the facility
- The opportunity costs, which include interest on the value of the grain in storage and insurance
- Grain management and husbandry costs, including storage losses, drying costs, electricity costs for grain handling, pest control costs and labour [11]

Detailed information about selecting, siting and fitting out silos, grain storage bags, sheds and bunkers is contained in the GRDC Grains Industry Guide Grain storage facilities: Planning for efficiency and quality.

13.3 Aeration during storage

Aeration of stored barley is the key non-chemical tool used to minimise the risk of insect infestations and spoiling through heat and/or moisture damage (Photo 1). [12]

Photo 1: *Storage with aeration is important for protecting Australia's markets.*

Source: DAF Qld

Grain aeration systems are generally designed to carry out either a drying or cooling function—not both. Aeration cooling can be achieved with airflow rates of 2–3 L/s/t delivered from fans driven by a 0.37 kilowatt (0.5 horsepower) electric motor while aeration drying can be achieved with fans delivering 15–25 L/s/t, typically powered by 7kW (10hp) electric motors. Low-capacity fans cannot push this drying front through the grain fast enough to dry grain in the top section of a stack before it turns mouldy. The risk of using high capacity fans for cooling is they increase grain moisture very quickly if run when ambient conditions are above 85% relative humidity. If a storage is only fitted with high capacity aeration drying fans, options for aeration cooling include; reducing fan run time, fitting a smaller fan for cooling, restricting the drying fan inlet to reduce its capacity or installing a variable speed drive to reduce fan speed. [13]

11 Stored Grain Information Hub (2016) Select grain stores carefully to control costs. http://storedgrain.com.au/select-grain-stores-carefully-to-control-costs/

12 GRDC (2012) Performance testing aeration systems. GRDC Grain Storage Fact sheet, August 2012, http://www.grdc.com.au/Resources/Factsheets/2012/08/Grain-Storage-Performance-testing-aeration-systems

13 GRDC (2013) Aerating Stored Grain: Cooling or Drying for Quality Control. A Grains Industry Guide, https://grdc.com.au/Resources/Bookshop/2013/06/Aerating-stored-grain

Choices

Knowing whether grain needs to be dried or cooled can be confusing, but there are some simple rules to follow:

- Grain that is dry enough to meet specifications for sale (12.5 %) can be cooled, without drying, to slow insect development and maintain quality during storage
- Grain of moderate moisture (up to 15%) will require aeration drying to reduce the moisture content to maintain quality during storage
- If aeration drying is not available immediately, moderately moist grain can be cooled for a short period to slow mould and insect development, then dried when the right equipment is available
- After drying to the required moisture content, cool the grain to maintain quality
- High-moisture grain (for example, 16% and higher) will require immediate moisture reduction before cooling for maintenance [14]

Aeration typically reduces stored grain temperatures by more than 10°C during summer (Figure 1), which significantly reduces the threat of a serious insect infestation. [15]

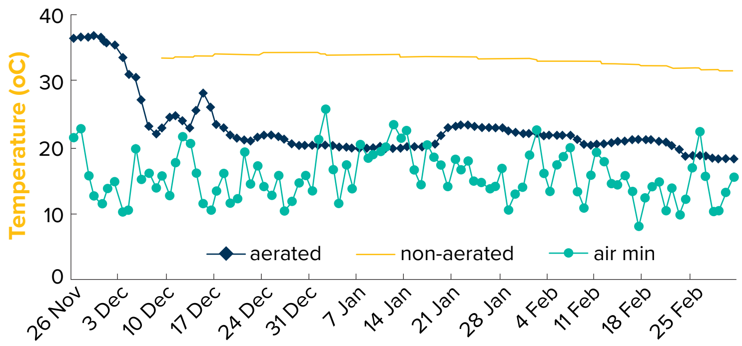

Figure 1: *Comparison of wheat grain temperatures in aerated and non-aerated silos.*

Source: Qld DAF

13.3.1 Aeration cooling

The aim of aeration cooling is to maintain grain quality during storage. By lowering grain temperature and creating uniformity through the grain stack, mould is less likely to develop. Lower temperatures are also less attractive for insects, conditions can slow (and even stop) insect development and seed viability is preserved.

Without aeration cooling, grain put into storage at warm harvest temperatures will hold these temperatures for a long time, in most cases taking months to cool down on its own.

Aeration cooling moves the air pockets around the grain, which evens out any hot or moist areas, creating a uniform stack. This prevents hot spots forming, which are ideal locations for mould and insects to develop and spread through the storage. [16]

14 GRDC (2013) Aerating Stored Grain: Cooling or Drying for Quality Control. A Grains Industry Guide, https://grdc.com.au/Resources/Bookshop/2013/06/Aerating-stored-grain

15 P Burrill (2013) Grain Storage Future pest control options and storage systems 2013–2014. GRDC Update Papers, 18 July 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Grain-Storage-Future-pest-control-options-and-storage-systems-2013-2014

16 GRDC (2013) Aerating Stored Grain: Cooling or Drying for Quality Control. A Grains Industry Guide, https://grdc.com.au/Resources/Bookshop/2013/06/Aerating-stored-grain

13.3.2 Aeration drying

Aeration drying requires a specifically designed system and is a much slower process than aeration cooling. In rare situations aeration cooling fans can reduce grain moisture slightly, but they cannot reliably reduce grain moisture to a safe level. In fact this 'drying' effect is likely to be simply a redistribution of moisture within the grain stack. Much higher airflow rates are required for aeration drying in order to push a drying front through the grain bulk.

Aeration drying relies on a high volume of air passing through the grain to slowly remove moisture. It is usually done in a silo with either high-capacity aeration fans, only partly filled with grain or a purpose-built drying silo. Aeration drying depends on warm, dry weather conditions. It is important to seek reliable advice on equipment requirements and correct management of fan run times, otherwise there is a high risk of reducing grain quality.

There are four key components to enable successful aeration drying:

- airflow rates of 15–25 L/s/t
- well-designed ducting for even airflow through the grain
- exhaust vents in the silo roof
- dry weather conditions. [17]

High moisture grain

Research shows cereals at 12% moisture content stored for 6 months at 30–35°C (unaerated grain temperature) will have reduced germination percentage and seedling vigour.

A national upper limit for moisture of 12.5% applies to barley at receival, but deliveries are usually in the range 10.5–11%. [18]

Special measures must be taken to minimise the risk of insect infestations or heat damage if the crop is harvested in damp conditions. [19]

Table 2: *The effect of grain temperature on insects and mould*

Grain temperature (°C)	Insect and mould development	Grain moisture content (%)
40–55	Seed damage occurs, reducing viability	
30–40	Mould and insects are prolific	>18
25–30	Mould and insects active	13-18
20–25	Mould development is limited	10-13
18–20	Young insects stop developing	9
<15	Most insects stop reproducing, mould stops developing	<8

Source: Kondinin Group

17 GRDC (2013) Aerating Stored Grain: Cooling or Drying for Quality Control. A Grains Industry Guide, https://grdc.com.au/Resources/Bookshop/2013/06/Aerating-stored-grain

18 Wheat Quality Objectives Group (2009) Understanding Australian wheat quality. GRDC, https://grdc.com.au/__data/assets/pdf_file/0011/202421/grdcwheatquality.pdf.pdf

19 GRDC (2013) Dealing with high-moisture grain. GRDC Grain Storage Fact sheet, June 2013, https://grdc.com.au/__data/assets/pdf_file/0024/152385/gsfs-7_highmoisturegrain_2013_lr_final-pdf.pdf.pdf

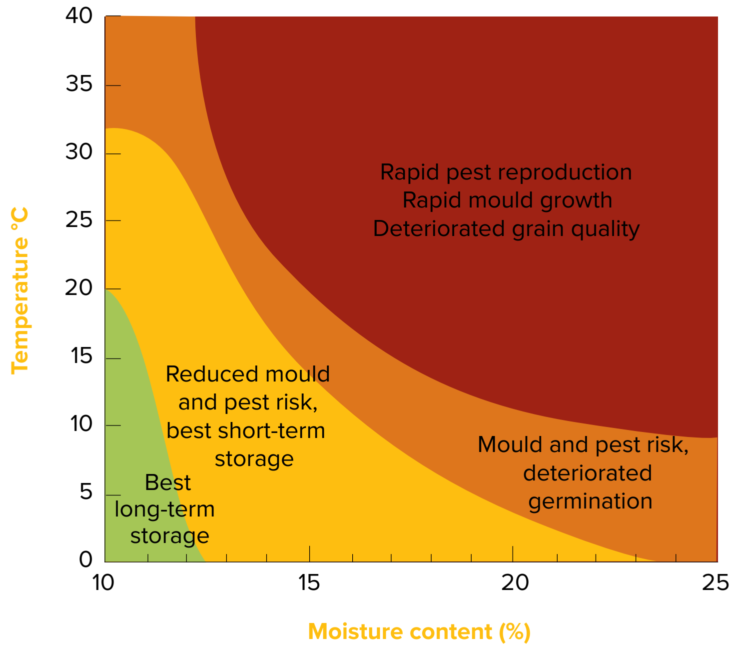

Figure 2: *Effects of temperature and moisture on stored grain.*

Source: CSIRO Ecosystems sciences as published in Grain Storage Fact Sheet—dealing with high-moisture grain

Blending

Blending is the principle of mixing slightly over-moist grain with lower-moisture grain to achieve an average below the ideal 12.5% moisture content. Using grain with a moisture content level up to 13.5%, blending can be an inexpensive way of dealing with wet grain, providing the infrastructure is available. If aeration is not available, blending must be evenly distributed, although aeration cooling does allow blending in layers.

If use of a grain dryer is not an option, grain that is over the standard safe-storage moisture content of 12% and up to the moderate moisture level of 15% can be managed by aerating until drying equipment is available. Blending with low-moisture grain and aerating is also a commonly used strategy (Figure 3).

MORE INFORMATION

GRDC (2016) Using aeration cooling for stored grain in Western Australia.

GRDC (2015) Solar-powered aeration cooling shows promise. Ground Cover Issue 119.

GRDC (2013) Aerating stored grain, cooling or drying for quality control. A Grains Industry Guide.

GRDC (2012) Performance testing aeration systems. Fact sheet.

GRDC (2013) Dealing with high-moisture grain. Fact sheet.

For general information on handling, drying and cooling see: Agridry Rimik Pty Ltd

https://www.agric.wa.gov.au/pest-insects/insect-pests-stored-grain?page=0%2C1

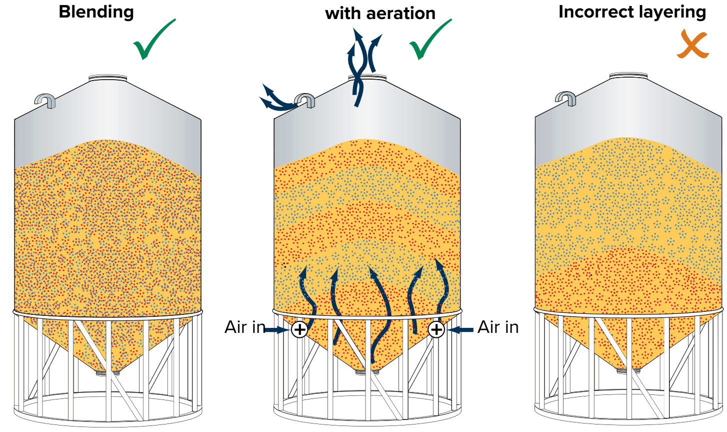

Figure 3: *Correct blending.*

Source: Kondinin Group

13.4 Hygiene

Effective grain hygiene and aeration cooling can overcome 75% of pest problems in stored grain. All grain residues should be cleaned out when silos and grain-handling equipment are not in use to help minimise the establishment and build-up of pest populations.

In one year, a bag of infested grain can produce more than one million insects, which can walk and fly to other grain storages where they will start new infestations. Meticulous grain hygiene involves removing any grain residues that can harbour pests and allow them to breed.

Grain pests live in protected, sheltered areas in grain-handling equipment and storage, and they breed best in warm conditions. Insects will also breed in outside dumps of unwanted grain (Photo 2). Try to bury grain or spread unwanted grain out to a shallow depth of <20 mm so insects are exposed to daily temperature extremes and other insect predators. [20]

20 GRDC (2013) Hygiene and structural treatments for grain storages. Fact sheet, June 2016, https://grdc.com.au/Resources/Factsheets/2013/06/Grain-Storage-Fact-Sheet-Hygiene-and-structural-treatments-for-grain-storages

Photo 2: *Poor grain hygiene undermines effective stored grain insect control.*

Source: DAF Qld

Grain insect pests may be divided into primary and secondary pests (Photo 3). Primary grain insects have the ability to attack whole, unbroken grains, while secondary pests attack only damaged grain, dust and milled products. [21]

Photo 3: *A primary grain pest, the lesser grain borer Rhyzopertha dominica is the most serious pest of stored grain in WA.*

Source: DAF Qld

Successful grain hygiene involves cleaning all areas where grain residues becomes trapped in storages and equipment. Grain pests can survive in a tiny amount of

21 DAFWA (2016) Insect pests of stored grain. Department of Agriculture and Food, Western Australia, https://agric.wa.gov.au/n/1167

MORE INFORMATION

[GRDC (2015) Starving Grain Bugs. Driving Agronomy Podcasts.]

[GRDC (2013) Hygiene and structural treatments for grain storage Fact sheet.]

[GRDC (2013) Western Region Stored grain pests – identification. Fact sheet.]

[GRDC (2013) Grain Storage Pest Control Guide Western Region. Fact sheet.]

[GRDC Grain silo hygiene Ground Cover TV2.]

grain, which can go on to infest freshly harvested clean grain. Harvesters and grain-handling equipment should be cleaned out thoroughly with compressed air after use.

After grain storages and handling equipment are cleaned, they should be treated with a structural treatment. Diatomaceous earth (DE) is an amorphous silica also commonly known as the commercial product Dryacide™ and is widely used for this purpose. It acts by absorbing the insect's cuticle or protective waxy exterior, causing death by desiccation. If applied correctly with good coverage in a dry environment, DE can provide up to 12 months' protection by killing most species of grain insects and with no known risk of resistance. It can be applied as a dry dust or slurry spray.

Although many cereal grain buyers accept the use of approved chemical insecticide structural treatments to storages, growers should avoid using them, or wash the storage out, before storing oilseeds and pulses. Several export and domestic markets require 'pesticide residue free' grain (PRF), and growers are advised to check with potential grain buyers before using grain protectants or structural treatments. [22]

Grain Trade Australia (GTA) stipulates standards for heat-damaged, bin-burnt, storage-mould-affected or rotten barley, all of which can result in the discounting or rejection of grain. GTA has nil tolerance to live, stored grain insects. [23]

Stored grain insects include: Rust-red flour beetle, Confused flour beetle, Saw-toothed grain beetle, Flat grain beetle, Warehouse moth, Indian meal moth and Warehouse beetle.

The lesser grain borer and rust-red flour beetle are some of the most common insect pests found in stored cereals. Other common species to watch for include weevils (*Sitophilus* spp.), sawtoothed grain beetle (*Oryzaephilus* spp.), flat grain beetles and rusty grain beetle (*Cryptolestes* spp.), psocids (booklice), Indian meal moth (*Plodia interpunctella*) and angoumois grain moth (*Sitotroga cerealella*). Another dozen or so beetles and mites, are sometimes present as pests in stored cereal grain.

Photographs and descriptions of stored grain pests can be found in the GRDC Stored grain pests identification. The Back Pocket Guide.

13.5 Grain protectants and fumigants

Grain Trade Australia is aware of cases where various chemicals have been used to treat stored grain that are not approved for grain or that particular grain type. When they are detected, an entire shipload can be rejected, often with serious long-term consequences for important Australian grain markets.

Accessing markets that require pesticide residue free (PRF) grain does not rule out the use of some fumigants, including phosphine (Photo 4). However, PRF grain should not have any chemical residues from treatments that are applied directly to the grain as grain protectants. Before using a fumigant, growers need to check with prospective buyers, because the use of some chemicals may exclude grain from certain markets. [24]

22 GRDC (2013) Hygiene and structural treatments for grain storages. Grain Storage Fact sheet, June 2013, https://grdc.com.au/Resources/Factsheets/2013/06/Grain-Storage-Fact-Sheet-Hygiene-and-structural-treatments-for-grain-storages

23 GTA (2013) Barley Trading Standards, 2015–16 season. Grain Trade Australia, August 2015, http://www.graintrade.org.au/sites/default/files/file/Commodity%20Standards/2015_2016/Section%2002%20-%20Barley%20Trading%20Standards%20201516%20Final.pdf

24 P Collins (2009) Strategy to manage resistance to phosphine in the Australian grain industry. Cooperative Research Centre for National Plant Biosecurity Technical Report, http://www.graintrade.org.au/sites/default/files/file/NWPGP/Phosphine%20Resistance%20Strategy.pdf

Photo 4: *Phosphine is widely accepted as having no residue issues.*

Source: DAF Qld

13.5.1 Pesticide residues

Pesticide residues in barley grain or dye from foam markers on barley grain can degrade the value of the premium product and seriously reduce its acceptability in local and overseas markets. Label rates, times of application and withholding periods are specified on all pesticide labels and have been set so that the Maximum Residue Levels (MRLs) are not exceeded.

Harvesting crops before the withholding period has expired or using product at rates above the labelled rate can leave unacceptable residues in the crop. To reduce the chance of unacceptable residues, it is up to the grower to select treatments that can be safely used. Good crop monitoring is needed to ensure problems which may require treatment before harvest are carried out within the harvest withholding periods.

Countries importing Australian barley are becoming more vigilant in their testing for chemical residues for food safety requirements and anything that may affect the processing quality. Importing countries who detect unacceptable residues will reject or down grade the shipment and increase their testing requirements. Further detection may result in a ban of Australian grain in that marketplace.

Observe the withholding periods and use the rate specified within the label limits to minimise any problems. [25]

13.5.2 Phosphine

Although phosphine has resistance issues, it is widely accepted as having no residue issues. The grains industry has adopted a voluntary strategy to manage the build-up of phosphine resistance in pests. Its core recommendations are to limit the number of conventional phosphine fumigations on undisturbed grain to three per year and to employ a break strategy. The break is provided by moving the grain to eliminate

25 J Russell, B Paynter, J Holmes (2008) Department of Agriculture and Food, Western Australia, Farmnote:325. Barley grain quality – pesticide residues and foam marker dye staining. https://www.researchgate.net/publication/274077755_Barley_grain_quality_-_pesticide_residues_and_foam_marker_dye_staining

pockets where the fumigant may fail to penetrate, and by retreating it with an alternative disinfestant or protectant. [26]

Effective phosphine fumigation can be achieved by placing the chemical at the rate directed on the label onto a tray and hanging it in the top of a pressure-tested, sealable silo. A ground-level application system is also an efficient application method, and these can be combined with a silo recirculation system on larger silos to improve the speed of gas distribution. After fumigation, grain should be ventilated for a minimum of 1 day with aeration fans running, or 5 days if no fans are fitted. A minimum withholding period of 2 days is required after ventilation before grain can be used for human consumption or stock feed. The total time required for fumigating ranges from 7 to 20 days depending on grain temperature and the storage structure.

Sealable silos

The Kondinin Group National Agricultural Survey 2009 revealed 85% of respondents had used phosphine at least once during the previous 5 years and, of those users, 37% used phosphine every year for the past 5 years. A GRDC survey during 2010 revealed only 36% of growers using phosphine applied it correctly—in a gas-tight, sealable silo.

Research shows fumigating in a storage that is not gas-tight does not achieve a sufficient concentration of fumigant for long enough to kill pests at all life-cycle stages. For effective phosphine fumigation, a minimum gas concentration of 300 parts per million (ppm) for 7 days or 200 ppm for 10 days is required (Figure 4). Fumigation trials in silos with small leaks demonstrated that phosphine levels are as low as 3 ppm close to the leaks (Figure 5). The rest of the silo also suffers from reduced gas levels. [27]

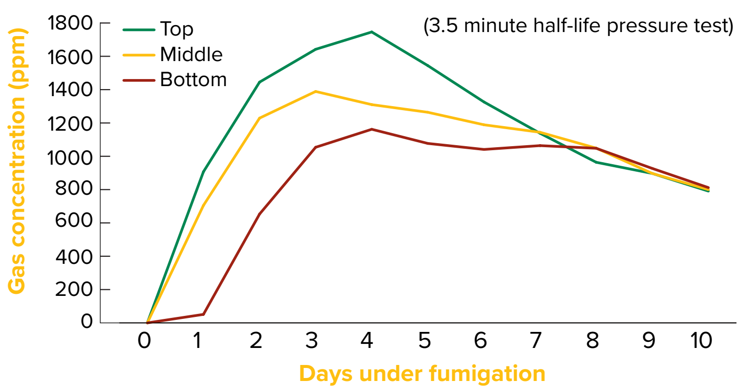

Figure 4: *Gas concentration in gas-tight silo.*

Source: DAF Qld

26 P Collins (2009) Strategy to manage resistance to phosphine in the Australian grain industry. Cooperative Research Centre for National Plant Biosecurity Technical Report, http://www.graintrade.org.au/sites/default/files/file/NWPGP/Phosphine%20Resistance%20Strategy.pdf

27 GRDC (2010) Pressure testing sealable silos. GRDC Grain Storage Fact sheet, September 2010, http://storedgrain.com.au/pressure-testing/

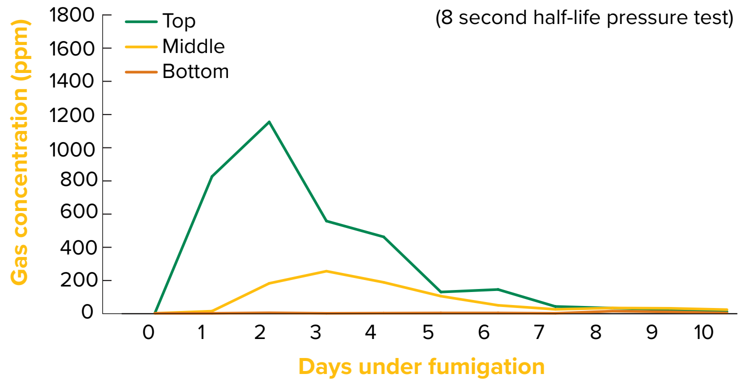

Figure 5: *Gas concentration in a non-gas-tight silo.*

Source: DAF Qld

Silo Bags

Silo bags as well as silos can be fumigated (Photo 5). Research conducted by storage specialists and growers in QLD found sufficient concentrations of phosphine can be maintained for the required time to fumigate grain successfully in a silo bag. Trials on a typical, 75-m-long bag containing approximately 240 t of grain successfully controlled all life stages of the lesser grain borer.

Photo 5: *Silo bags can also be fumigated.*

Source: DAF Qld

When using phosphine in silos or silo bags, it is illegal to mix phosphine tablets directly with grain because of tablet-residue issues. Trays in silo bags are not practical, therefore tablets are placed in a perforated conduit to contain tablets and spent dust. The 1-m tubes are speared horizontally into the silo bag and removed at the end of the fumigation. Trial results suggest that the spears should be no more than 7 m apart and fumigation should occur over 12–14 days (Figure 6). In previous trials, when spears were spaced 12 m apart, the phosphine gas took too long to diffuse throughout the whole bag. [28]

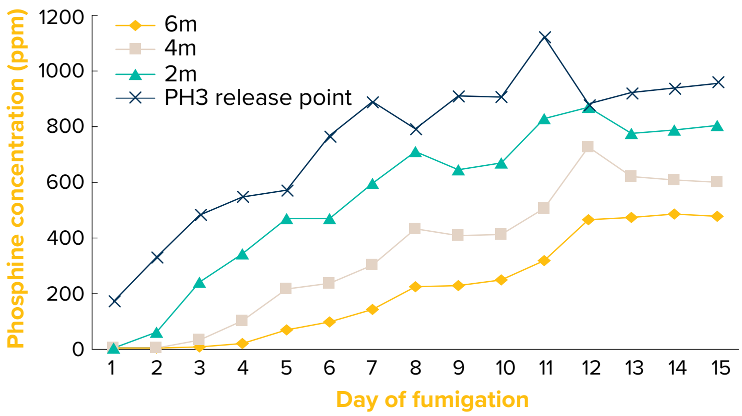

Figure 6: *Spread of phosphine gas in a silo bag from a release point to gas-monitoring lines at 2, 4 and 6 m along a silo bag.*

MORE INFORMATION

GRDC Grain bags–fumigation. Ground Cover TV.

GRDC (2011) Fumigating with phosphine, other fumigants and controlled atmospheres. Grains Industry Guide.

13.5.3 Alternative strategies

While phosphine is still the most commonly-used gas fumigant for controlling pests in stored grain, there are other options. Each of the alternatives still requires a gas-tight, sealable silo and are currently more expensive than using phosphine, but they offer an alternative for resistant pest species. Nitrogen (N) and carbon dioxide (CO_2) carry the added advantage of being nonchemical control alternatives. Both N and CO_2 methods of control are sometimes referred to as controlled atmosphere (CA) because they change the balance of natural atmospheric gases to produce a toxic atmosphere.

Carbon dioxide

Treatment with CO_2 involves displacing the air inside a gas-tight silo with a concentration level of CO_2 high enough to be toxic to grain pests. This requires a gas-tight seal, measured by a half-life pressure-test of no less than five minutes. To achieve a complete kill of all the main grain pests at all life stages, CO_2 must be retained at a minimum concentration of 35% for 15 days. This method of fumigation is not recommended when temperatures are below 15°C. At temperatures below 20°C CO_2 is less effective because insects are less active so the concentration must be maintained for an extended period.

Nitrogen

Grain stored under N provides insect control and quality preservation without chemicals. It is safe to use, environmentally acceptable and the main operating cost is electricity. It also produces no residues so grains can be traded at any time, unlike chemical fumigants that have withholding periods. Insect control with nitrogen involves a process using Pressure Swinging Adsorption (PSA) technology, modifying the atmosphere within the grain storage to remove everything except N, starving the pests of oxygen.

The application technique is to purge the silo by blowing N-rich air into the base of the silo, forcing the existing, oxygen-rich atmosphere out the top. PSA takes several hours of operation to generate 99.5% pure N and before the exhaust air has a reduced concentration of 2% oxygen. At 2% oxygen adult insects cannot survive,

28 P Burrill, A Ridley (2012) Silo bag fumigation. GRDC Grains Research Update, Northern Region, Issue 66,

providing this concentration is maintained for 21 days with a grain temperature above 25°C. Anything less will not control all life stages —eggs, larvae and pupae. For grain below 25°C this period is extended to 28 days. The silo must be checked the day after fumigation and may need further purging to remove oxygen that has diffused from the grain.

Nitrogen storage will also maintain the quality of canola and pulses by inhibiting the respiration process that causes oxidation, which leads to seed deterioration, increased free fatty acids and loss of colour. [29]

It's all in the seal

Replacing oxygen in grain storage silos with nitrogen has proven an effective way to remove insects at all stages of their life cycle, leaving stored grain—be it wheat or canola—preserved, residue-free and subject to no withholding periods.

Nitrogen is also the preferred storage option, says Western Australia grower Doug Clarke, who is the earliest adopter of the technology in its on-farm form.

Mr Clarke made the switch several years ago on his Lake Grace property, and has made his silos available to Murdoch University researchers led by stored-grain expert Professor YongLin Ren, with support from the GRDC.

Mr Clarke has hosted visitors over the years, including overseas buyers, and says he has learnt the extent to which insecticide-free grain is preferred by buyers.

While he says the system is performing well, he is committed to continuous improvement.

However, one challenge is that there is currently no price signal favouring residue-free grain to compensate for the investment and the extra work associated with nitrogen-based storage.

In relation to the technology itself, Mr Clarke has no issue with existing oxygen-purging systems. He says the nitrogen generator needed to purify nitrogen from the atmosphere and pump it into a silo is a machine developed by the oil industry, which is widely available.

"At a rate of 30 cubic metres an hour, it costs about $5 worth of diesel to purge a silo of oxygen all the way down to 0.05 per cent total content," he says. "Best of all, insects never acquire resistance."

Another challenge relates to infrastructure: silos leaking.

"The standards for sealed silos are too low for nitrogen storage of grain," Mr Clarke explains. "The accepted level on the seals for a silo is the loss of half an inch (12.7 millimetres) of water pressure in three minutes."

The oxygen in the silo needs to be purged long enough to kill all insects. Mr Clarke has identified a relationship between eradication time (for all stages in an insect's life cycle) under nitrogen and grain temperature.

The eradication time is as low as one week at high temperatures, at 20°C it blows out to three weeks, and below that temperature he says it does not work.

29 C Warrick (2011) Fumigating with phosphine, other fumigants and controlled atmospheres: Do it right—do it once: A Grains Industry Guide. GRDC Stored Grain Project, January 2011, https://grdc.com.au/__data/assets/pdf_file/0025/206791/fumigating-with-phosphine.pdf.pdf

It is these circumstances that have created resistance to insecticides and an interest in the latest sealing technology.

"What I am saying is that the better the seal, the better control you have under any fumigant. We need to be looking to the latest sealing technology, including polymers and 3D printers," he says. "The area that now needs improving is the silo manufacturing." [30]

Sulfuryl fluoride

According to research, sulfuryl fluoride (SF) has excellent potential as an alternative fumigant to control phosphine-resistant grain storage pests (Table 2). It is currently registered in Australia as a grain disinfestant. Supplied under the trade name 'ProFume®', SF can be used only by a licensed fumigator.Annual resistance-monitoring data were analysed to assess the impact of SF as an alternative fumigant to phosphine. This revealed that after the introduction of SF in central storages across the northern and southern grain regions in 2010, there was a 50% reduction in the incidence of strongly phosphine-resistant populations of rusty grain beetle at the end of the first year, and the downward trend is continuing. Complementary laboratory experiments have shown that phosphine resistance does not show cross-resistance to SF, which is an additional advantage of using SF. [31]

VaporMate®

VaporMate® (active ingredient ethyl formate 166.7 g/kg) is approved for use in stored cereals and oilseeds. It is registered to control all life stages of the major storage pest insects—lesser grain borer, rust-red flour beetle (*Tribolium* spp.), sawtoothed beetle, flat grain beetles, storage moths and psocids (booklice). However, it does not fully control all stages of rice weevil. It must only be used by a licensed fumigator.

Protectants

Two grain protectants are now available became available in 2013:

- K-Obiol (active ingredients deltamethrin 50 g/L, piperonyl butoxide 400 g/L). Features acceptable efficacy against the common storage pest, lesser grain borer, which has developed widespread resistance to current insecticides. Insect-resistance surveys in the past consistently detected low levels of deltamethrin-resistant insect strains in the industry. Therefore resistant populations could increase quickly with widespread excessive use of one product. A product stewardship program has been developed to ensure correct use of the product.
- Conserve On-Farm (active ingredients (chlorpyrifos-methyl 550 g/L, S-methoprene 30 g/L, spinosad 120 g/L) to control most major insect pests of stored grain, including the resistant lesser grain borer. Maximum residue limits have been established with key trading partners and there are no issues with meat residue bioaccumulation. [32]

MORE INFORMATION

GRDC (2014) Grain Fumigation Guide. Fact sheet.

GRDC (2011) Stay safe around grain storage. Fact sheet.

APVMA: Metal phosphides—priority 5

30 G Braidotti (2015) It's all in the seal. GRDC Ground Cover, Issue 119, https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-119--Grain-storage/Its-all-in-the-seal

31 M Nayak (2012) Sulfuryl fluoride—A solution to phosphine resistance? GRDC Grains Research Update, Northern Region, Issue 66, http://storedgrain.com.au/wp-content/uploads/2014/05/Northern-Update-Issue-66.pdf

32 P Burrill (2013) Grain Storage Future pest control options and storage systems 2013–2014. GRDC Update Papers, 18 July 2013, https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/07/Grain-Storage-Future-pest-control-options-and-storage-systems-2013-2014

13.6 Monitoring barley

Growers are advised to monitor all grain in storage at least monthly. During warm periods in summer, if grain moisture content is near the upper end of the safe storage moisture content, monitoring every two weeks is advisable. Insect pests present in the on-farm storage must be identified so growers can exploit the best chemical and/or non-chemical control measures to control them.

Barley for domestic or export use must not contain live storage pests, and feed grades can lose nutritional value and palatability through infestations. Keeping storage pests out of planting seed grain is also important because they can reduce the germination and vigour quality of seed, with serious consequences for the next barley crop.

When monitoring stored grain through sieving, trapping and quality inspections, growers should keep records of findings. If possible, grain temperature should also be checked regularly. Any grain treatments applied should be recorded (Photo 6). [33]

Photo 6: *Keep records of findings from stored grain insect monitoring.*

Source: DAF Qld

Key points to follow when monitoring for grain insect pests:

- Sample and sieve grain from the top and bottom of grain storages every four weeks for early pest detection. Pitfall traps installed in the top of the grain store will also help with early detection of storage pests
- Holding an insect sieve in the sunlight will encourage insect movement, making pests easier to see. Sieve samples onto a white tray to make small insects easier to see. Sieves should have 2-mm mesh and need to hold at least 1 L of grain
- To identify live grain pests, place them in a clean glass container. Briefly warm the jar in the sun to encourage insect activity. Weevils and sawtoothed grain beetles can walk up the walls of the glass easily, but flour beetles and lesser grain borer cannot. Look closely at the insects walking up the glass—weevils have a curved snout at the front and sawtoothed grain beetles do not [34]

33 GRDC (2010) Aeration cooling for pest control. GRDC Grain Storage Fact sheet, September 2010, http://storedgrain.com.au/wp-content/uploads/2014/09/GSFS-5_AeratCooling-July14.pdf

34 GRDC (2013) Stored grain pests—identification. Northern and Southern regions. GRDC Grain Storage Fact sheet, June 2013, https://grdc.com.au/resources-and-publications/all-publications/factsheets/2013/06/grain-storage-fact-sheet-stored-grain-pests-identification

MORE INFORMATION

[GRDC (2009) Stored grain pests, Western Region. Fact sheet.]

[GRDC (2014) Vigilant monitoring protects grain assets. Fact sheet.]

13.6.1 GRDC Stored grain App

An App is available to record storage details such as grain type, variety, grade, quantity, paddock/source, date filled, date emptied and purchaser for farm records and quality assurance tracking. Each time a storage is monitored the app allows recording of the date, temperature, moisture content, pests identified, treatment details and any other notes.

A key feature of this application is the ability to record grain storage details and monitoring Records at the storage site regardless of mobile reception or data speed.

Simply enter the desired records and when the grower is next in mobile reception range, records can be synchronised between multiple mobile devices and/or exported to Excel.

To download go to GRDC storedgrain

See Stored Grain App–Help on the Stored Grain Information Hub website.