GRDC

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GRAIN STORAGE

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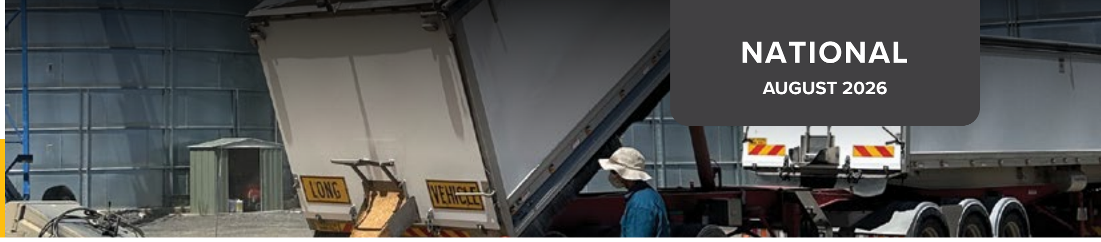

Start here for answers to your immediate grain storage issues

Grain storage — planning and purchasing

Economics of on-farm storage

Safety around grain storage

Grain storage insect pest identification and management

Preventing stored-grain pest infestations

Managing insect pests in stored grain

Managing high-moisture grain

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Introduction

A.1 On-farm grain storage

On-farm grain storage plays an important role in many Australian cropping operations and growers who manage their storage facilities and operations well can be rewarded through preferred-supplier partnerships with key grain traders. Grain traders and buyers are increasingly pursuing growers who can maintain grain quality through best-practice storage management allowing savvy growers to become ‘price makers’ rather than ‘price takers’.

On-farm storage systems are a significant investment to set up and manage. Any potential return on investment in on-farm storage should be compared to other investment options, such as buying more land or upgrading machinery, to determine the best use of capital. Grower returns from an investment in on-farm storage vary depending on their scale, crops grown, access to bulk handlers and distance from domestic markets.

In the same way growers ensure they take a strategic approach to managing the production of their crops, a strategic approach to grain storage is also required for optimal end-product performance. It’s no longer acceptable to empty grain into a silo at the back of the shed and forget about it for months on end. A strategic development plan for investment in grain storage provides greater opportunity to manage variable production years and crops whilst ensuring grain quality.

Successful on-farm grain storage relies on understanding and applying best-practice storage management. This manual brings together practical information, research findings, links to additional resources and industry contacts to help growers confidently manage grain quality and reduce storage risks.

An integrated approach combining grain hygiene, aeration cooling, regular monitoring and effective fumigation provides the best opportunity to preserve grain quality while minimising insect problems. By adopting these practices and using fumigants responsibly, growers can help slow the development of phosphine resistance and protect the long-term effectiveness of Australia’s most important stored-grain fumigant.

Ultimately, good grain storage management protects grain quality, improves marketing flexibility and saves both growers and the Australian grains industry millions of dollars through reduced losses and improved pest control.

Photo 1: *Well-managed on-farm grain storage can be a profitable enterprise in its own right. (Source: Chris Warrick, Primary Business)*

Grain storage — planning and purchasing

VIDEOS

GCTV Mixed storage strategy

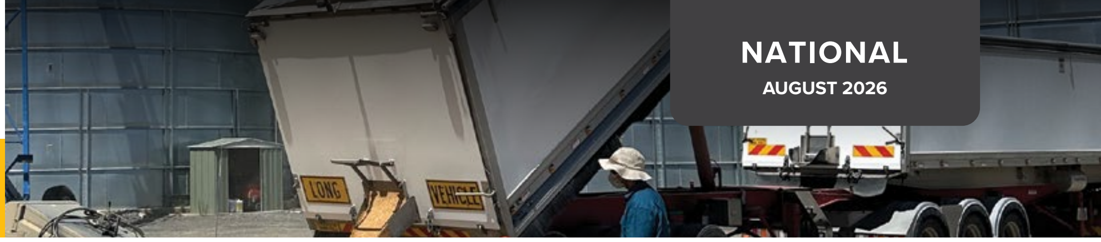
On-farm grain storage systems are available in a wide range of sizes and configurations to suit different farming businesses. Careful planning is essential to ensure the chosen system meets both current and future storage requirements while providing the best return on investment.

Depending on the storage system selected, on-farm grain storage can provide either short-term or long-term storage. Whether the objective is to improve harvest logistics, increase marketing flexibility or preserve grain quality, there are storage options to suit a range of business goals.

There are no knock-down insecticides for treating grain storage pest infestations. Effective insect control now relies on gas-tight storages for fumigation or the use of controlled atmospheres. As a result, selecting the right storage system and planning for effective pest management has become more important than ever.

Harvest is the ideal time to assess future grain storage requirements. It provides an opportunity to identify constraints, bottlenecks and opportunities for improvement while they are still fresh in mind, helping guide future investment decisions before the next cropping season begins.

Photo 2: *Flat-bottom silos (photo top) and cone-bottom silos (photo bottom) remain the most popular on-farm grain storage options. (Source: Chris Warrick, Primary Business)*



1.1 Grain storage options

Costs and storage flexibility can vary between grain storage options as can longevity of the investment.

Table 1 identifies the major on-farm grain storage options, their advantages and disadvantages.

Silos are the most common method of storing grain in Australia, constituting 61 per cent of all on-farm grain storage facilities nationally (see Figure 1).

Silos come in a variety of configurations, including flat-bottom or cone-bottom, and both are available as gas-tight sealable or non-sealed, aerated and non-aerated.

The balance of on-farm grain storage facilities can be split between grain storage bags (17 per cent), sheds (12 per cent) and pits, bunkers or rings (4%).

Grain-storage bags are increasing in popularity as a short-term storage solution to assist harvest logistics. With careful management growers can also use grain bags to provide short-term marketing opportunities.

For similar storage timeframes to grain storage bags, and where options are limited, growers can also temporarily store grain in sheds during harvest — provided they have been well prepared.

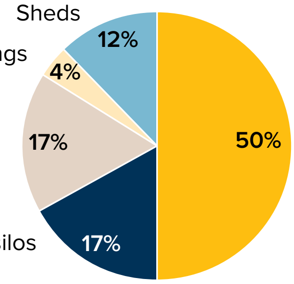


Figure 1: *On-farm grain storage*

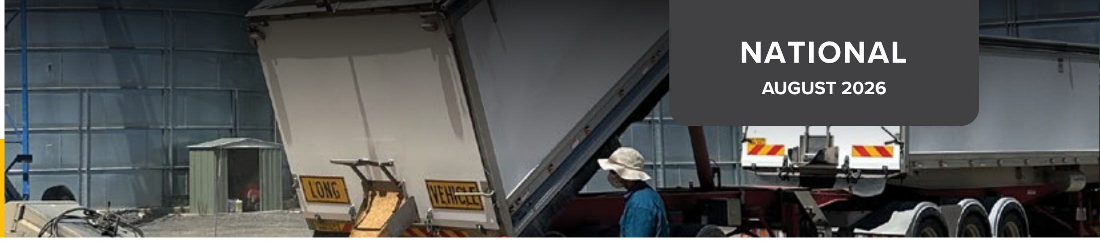
Source: Kondinin Group NAS 2024

VIDEOS

Sealable silos

Table 1: Advantages and disadvantages of grain storage options

Storage type	Advantages	Disadvantages
Gas-tight sealable silo	• Gas-tight sealable status allows phosphine and controlled atmosphere options to control insects • Easily aerated with fans • Fabricated on-site or off-site and transported • Expected 30 year plus service life • Simple in-loading and out-loading • Easily administered hygiene (cone-bottom particularly) • Can be used multiple times in-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



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Adding on-farm grain storage – considerations

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Storage options

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New silo considerations

Table 1 (Cont.): Advantages and disadvantages of grain storage options

Storage type	Advantages	Disadvantages
Non-sealed silo	• Can be cheaper than sealable silos	• Silo cannot be used for fumigation — see phosphine label • No insect control options, only prevention strategies such as protectants, hygiene, structural treatments and aeration cooling.
Grain storage bags	• Low initial cost • Can be laid on a prepared pad in the paddock • Provide harvest logistics support • Can provide segregation options • Are all ground operated • Can accommodate high-yielding seasons	• Requires purchase or lease of loader and unloader • Increased risk of damage beyond short-term storage • Limited insect control options, fumigation only possible under specific protocols • Requires regular inspection and maintenance which needs to be budgeted for • Must be fenced off • Prone to attack by mice, birds, foxes etc. • Limited wet weather access if stored in paddock • Need to dispose of bag after use • Single-use only
Grain storage sheds	• Can be used for dual purposes • 30 year plus service life • Generally low cost per stored tonne • Gas-tight sealable options available	• Aeration systems require specific design • Risk of contamination from dual purpose use • Typically cannot be used for fumigation (unless built specifically as a sealable storage at additional cost). • Vermin control is difficult • Difficult to unload
Bunkers	• Low capital cost • Flexible size	• Requires tarp removal and replacement for loading and unloading • Comparatively more difficult to unload • Typically not suited to fumigation unless set up to be sealable • Requires suitable location and groundworks to prevent water ingress

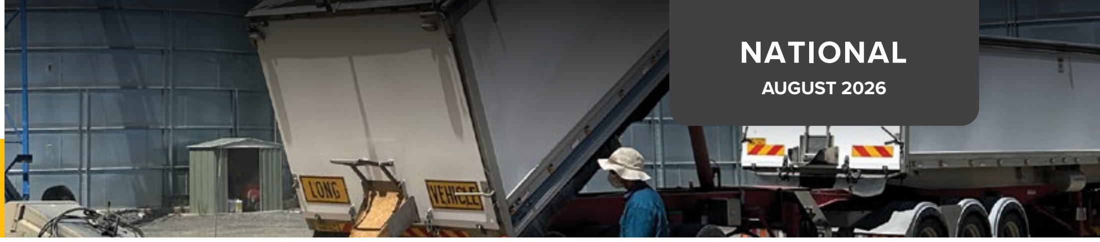
Source: Kondinin Group

1.1.1 Silos

Silos remain the most common form of on-farm grain storage and are available in both cone-bottom and flat-bottom configurations. Compared with grain bags, sheds and bunkers, silos generally require a higher initial investment. However, they provide the greatest flexibility for preserving grain quality through gas-tight fumigation, controlled atmospheres, aeration cooling and aeration drying. They are available in a wide range of sizes and designs and, when properly maintained, offer a long service life.

Fumigation

A gas-tight sealable silo will ensure phosphine, or other fumigants and controlled atmospheres, are maintained at a sufficient concentration to kill insects through their complete life cycle of eggs, larvae, pupae and adult.



VIDEOS

Pressure relief valves

VIDEOS

Condensation drains on silos

Be aware of cunning marketing terminology such as 'fumigatable silos'. Although such a silo might be capable of sealing with modifications, a gas-tight sealable silo needs to be tested onsite to meet Australian Standard (AS 2628–2010) after installation.

Gas-tight sealable silos also can be used for alternative methods of insect control including controlled atmospheres of inert gasses, such as carbon dioxide or nitrogen.

Size and construction

Silos can be delivered to the farm fully assembled or constructed on site. Transportable silos are generally limited to around 150 t capacity due to road transport restrictions, while larger silos are typically erected on site.

Cone-bottom silos are self-emptying, making them easier to clean than flat-bottom silos. Site-built cone-bottom silos typically range from 150–300 t, although capacities of up to 3000 t are available. Compared with flat-bottom silos, they generally have a higher capital cost per tonne of storage capacity.

Flat-bottom silos typically range from 800–4000 t, with capacities of up to 15,000 t available. As silo size increases, so does the number of sheet joints and the structural loads acting on the storage. This makes achieving and maintaining a gas-tight seal more challenging.

If fumigation is a priority, choose a well-engineered silo designed and constructed to achieve and maintain a gas-tight seal under Australian conditions. Quality construction generally comes at a higher initial cost but is typically repaid through a longer service life, improved reliability and more effective insect control.

Silo capacity is commonly quoted in tonnes, usually based on wheat. Because the bulk density assumed for wheat varies between manufacturers, always confirm the bulk density used when comparing storage capacities.

To determine tonnage capacity, multiply the cubic capacity by the volumetric density of the grain (see Table 2 for typical grain bulk densities). Some manufacturers allow for compaction of grain in the storage and may apply a higher bulk density than indicated in Table 2.

Capacity can also be quoted as cubic metres (m^3), which can be useful when comparing quotes with different wheat bulk densities used in the calculation.

Table 2: Typically used loose-fill bulk densities

Grain	Bulk density (t/m^3)*
Barley	0.68
Canola	0.67
Chick Peas	0.74
Cotton seed	0.40
Lentils	0.83
Lupins	0.80
Maize	0.72
Mung beans	0.75
Sorghum	0.73
Sunflower seed	0.42
Triticale	0.68
Wheat	0.77

*Note: Bulk density values vary according to moisture content and variety. The values shown are loose-fill bulk densities and do not account for compaction, which can result in higher bulk density values depending on storage type and grain depth

Source: Kondinin Group

Photo 3: *The choice between flat- and cone-bottom silos should consider unloading efficiency, grain segregation, optimum silo size, loading and unloading logistics, and cost. (Source: Chris Warrick, Primary Business)*

Longevity

A well-built, aerated, quality gas-tight sealable silo constructed to meet the Australian standard (AS 2628–2010) with a thorough maintenance regime could be expected to provide at least 30 years of serviceable life before major repairs may be required.

Aeration cooling

Silos enable simple provisions for aeration after harvest to cool grain and maintain a uniform moisture profile.

Aeration cooling of grain in storage can slow or stop insect pest life cycles.

Depending on the temperature reductions achieved, this can deliver significantly-reduced insect numbers.

Photo 4: *Aeration cooling is relatively inexpensive and can offer substantial benefits. (Source: Ben White, Kondinin Group)*

For more information on aeration cooling, see Section 5.4 Aeration cooling.

Aeration drying

Specific drying silos are designed to maximise drying efficacy and have high airflow rates of between 15-20 litres per second per tonne (L/s/t) of storage.

Specially-designed drying silos often have a truncated, or secondary, base cone to assist in the efficiency of drying stored grain.

Drying with ambient air requires a relative humidity below the equilibrium relative humidity of the grain. In regions where higher relative humidity is common, adding heat to the intake air increases its moisture-holding capacity, improving its ability to remove moisture from the grain.

Heated-air drying typically requires airflow rates exceeding 20 L/s/t.

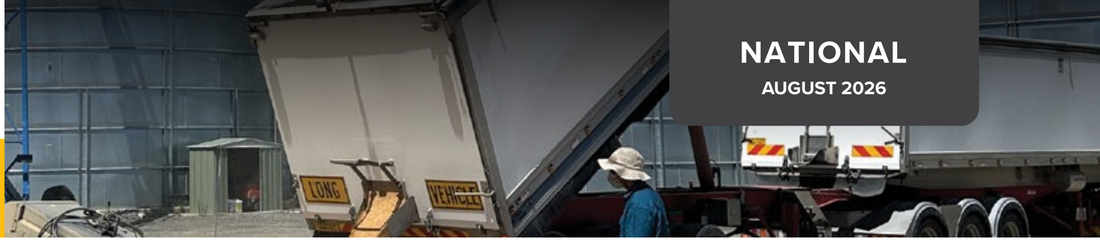
For more information on aeration drying, see Section 7 Managing high-moisture grain.

VIDEOS

On-farm Grain Storage: Silo maintenance

VIDEOS

Extend the life of your silo seals



VIDEOS

[Ladders required on silos](#)

SAFETY TIP

Safety should be a primary consideration when working with grain storage infrastructure. This symbol highlights important safety information throughout the publication.

Capital investment

As a permanent infrastructure fixture on a farm, silos require a high initial capital investment especially when foundation costs are included. When considering the cost of storage over the expected life of the silo, however, silos are comparatively cost effective with other types of storage.

For more information on the economics of investing in silos, see Section 2 Economics of on-farm grain storage.

Safety

Working at heights can be dangerous without the appropriate safety precautions. In the case of silos, this can mean working up to 16 m or more off the ground.

When grain is stored for longer than a month, regular inspection through the top hatch is required. Safer silo designs now incorporate ground-operated lids, caged ladders, platforms and top rails to minimise the risk of operators falling. Facilities for harness attachments, which should be worn by all operators climbing silos, are also fitted.

For more information on silo safety, see Section 3 Safety around grain storage.

Photo 5: *Caged and platformed access ladders improve safety when climbing the silo to inspect stored grain. (Source: Ben White, Kondinin Group)*

MORE INFORMATION

Kondinin Group: Grain Silos Research Report

VIDEOS

Pressure testing silos

VIDEOS

Buying Silos

Silo buyers' checklist

- Aerated, gas-tight sealable silos should always be the preferred option.

Essential features of a gas-tight sealable silo

- Certified AS2628-2010 and manufacturer will conduct pressure test after construction.
- Has a pressure relief valve large enough to suit the silo and conditions with clear markings for pressure testing.
- Has a facility to add air, for example, a tyre valve stem, water trap or blower port which can be used to conduct a half-life pressure test.
- Has high density rubber seals (EPDM) with strong memory and UV resistance.
- Lasting seals between sheet joins, rivets, screws and bolts. Maintains seal integrity when filled.
- Has latches for pressure testing the silo when empty and providing even seal pressure.
- Has aeration cooling fans sized appropriately to deliver a minimum of 2-4 litres per second per tonne of capacity for cooling grain (under grain back pressure).
- Has fans sized appropriately to deliver 15-20 litres per second per tonne of capacity if planning to dry grain (under grain back pressure).
- Automatic controller capable of operating fans for cooling and/or drying (aftermarket or manufacturer supplied)
- Outlet access for unloading should be simple to operate and permit ample auger access.
- Has an aeration distribution plenum to disperse air evenly throughout the grain.
- Allows easy and safe ground access for cleaning out the silo.
- Has an easy to clean design including aeration ducting, particularly in flat-bottom silos.
- Has a workplace health and safety compliant ladder and platform to access the inlet lid and an inspection opening in the roof.

SAFETY TIP

- Is fabricated with a sturdy steel design with sound weldments and a galvanised or quality painted finish.
- Has a sealed passive recirculation system if larger than 150-tonnes capacity, or a powered recirculation system if larger than 300-tonnes capacity which are UV stabilised and will not compromise seal integrity in the future.
- Have wall sight glasses or level sensors to indicate grain level particularly near the top and bottom of the silo to assist filling and emptying.
- A chalk-board patch painted on the silo base can be useful for recording grain and treatment details.
- Consider grain segregation requirements when determining silo size. Smaller silos allow better segregation but require more frequent auger moves. A variation of sizes often works well.
- Ensure adequate venting is fitted to the roof of silos, they should be easy to clean and near the roof access ladder to enable maintenance.

Fumigation chambers

- If a sealed fumigation application chamber for phosphine tablets is fitted, ensure it has a sufficiently large tray to spread tablets without excessive stacking.
- Trays should be easily removed for residual disposal.
- The chamber should also have passive or active sealed recirculation to carry released gas out of the chamber.

1.1.2 Grain storage bags

Since their introduction to Australia in the early 2000s, best-practice management techniques have evolved to improve the longevity of bag storage. They can be used as short-term storage in the paddock or medium-term storage if regularly maintained at well-prepared, centralised sites.

Capacity

Typical storage capacity is around 240 t, although bags with capacities of up to 500 t are also available.

Take care when purchasing grain bags, as the quality of bag materials varies. Bags designed for silage storage are not recommended for grain storage because they are more prone to failure.

Using grain storage bags successfully

Successful use of grain bags as an on-farm grain storage option requires a carefully-prepared site. An elevated, compacted, well-drained pad provides optimal results where no stubble (which can harbour vermin) or rocks can tear the grain storage bags as they are being filled and unloaded. Combining bags to centralised purpose-built sites has many advantages in managing, maintaining and out-loading, therefore extending the likely storage period before issues arise.

Fill rates can be up to 10-12 tonnes per minute. Always fill bags on firm compacted ground and ensure brake settings on the filler are set to ensure the appropriate stretch of the bag is achieved. While typically a 10 per cent stretch, this can be adjusted down for hot weather conditions or up for cool ambient weather. Check filled bags regularly and vigilantly for cuts, nicks and holes and patch these with an adhesive polyurethane sealant or bag adhesive tape available from the bag supplier.

Capital investment

The two pieces of equipment required for loading and unloading grain storage bags cost around $50,000-80,000 each.

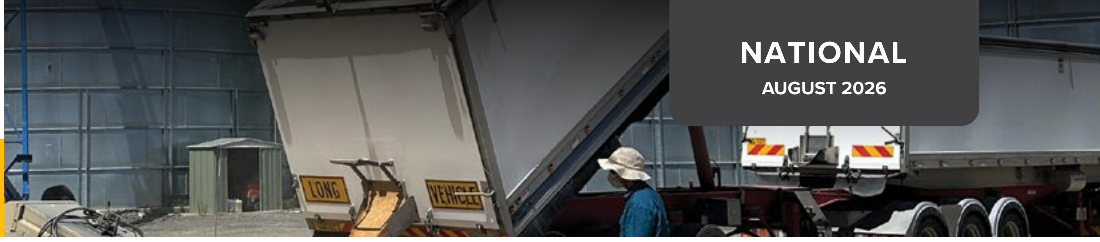
This equipment can be hired, although owning it can reduce the pressure of having to get grain in and out of the bags within a specified timeframe as demand for this hire equipment is high at the peak of harvest.

The bags themselves are single-use and cost around $5-$6 per tonne stored.

Consider site-preparation, including any earthworks and fencing requirements, time and labour costs for maintenance when calculating the comparative costs of using grain bags.

Longevity

While longer-term storage is possible in bags if well managed, they are best suited to short-term storage of a few months. Beyond this, the risk of grain losses and spoilage increases significantly.



VIDEOS

GCTV: Grain bags – Fumigation

VIDEOS

GCTV: Grain bags — A grower's perspective

VIDEOS

GCTV: Grain bags — Best practice

Pest and insect control in grain bags

Fumigation in bags has been proven in Australia as an option if the correct method of application and venting is followed. Success relies on the bag not being compromised with holes. Phosphine meters are required to monitor gas concentration during the fumigation and venting periods.

Trials indicate phosphine placement must be no more than seven metres apart along the bag, inserted in such a way that the bag can be resealed during fumigation and removed so grain is not contaminated with residue. One-metre lengths of PVC pipe with a series of 1 mm slots cut along the top and inserted horizontally has been proven to evenly distribute gas over a 10 day period.

Venting methods trialled have included propping open the finish end of the bag and inserting the suction side of a fan into the start end of the bag to draw the gas out. A passive ventilation option is to use 50 mm slotted PVC pipe inserted every 7 m along the bag on alternate sides, with the ends of the pipe left open after the phosphine is removed.

The time taken to reach the clearance level directed by the label can vary by method and should be checked with a low-range phosphine meter. If using a fan, a few days can suffice to reach clearance levels, but if passively venting, allow at least 35 days.

Paying a commercial fumigator to use sulfuryl fluoride is another option for fumigating grain bags. Allow 20 days for the process – fumigation controlling all life stages, passive venting and withholding.

In addition to insects, vermin including mice and birds can attack grain bags. Outside baiting, reducing habitat provision and food sources (including regular checking and patching of bags where required) is the best way to reduce vermin risk.

Access

One often-overlooked aspect of using grain-storage bags in the paddock is their accessibility after harvest. Unless the bags are placed on, or near, an all-weather access road, they can be difficult to unload if wet weather conditions prevail post-harvest. The pad site needs to be large enough for trucks and machinery for bag unloading and allow access in wet conditions.

1.1.3 Sheds and bunkers

Photo 6: *Grain storage sheds can provide dual functionality but hygiene is imperative to avoid contamination. (Source: Chris Warrick, Primary Business)*

Bunkers are commonly used by bulk handling companies, but require careful site preparation, labour for handling large tarp covers and machinery to move grain on and off the grain stack. An elevated site is required that can be graded to a camber shape to run water away. Bunker walls can range from simple 0.5 m soil banks to purpose-built concrete walls with clamps for securing tarps.

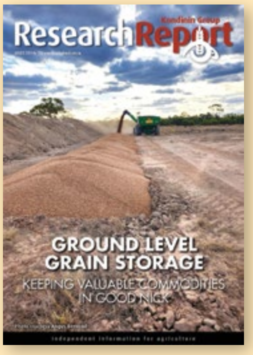
VIDEOS

Considering temporary grain storage? Bunkers are an option

MORE INFORMATION

Bunker Storage Information references

MORE INFORMATION



Ground Level Grain Storage (Kondinin Group Research Report)

Treating insect infestations in sheds and bunkers can be more challenging, as effective fumigation relies on achieving a high level of gas-tight sealing to contain the fumigant. More recently, purpose-built grain sheds have been designed, constructed and tested to achieve gas-tight sealing.

Sheds and bunkers offer the flexibility to store grain as well as other products, including fertiliser and machinery. However, this versatility increases the importance of maintaining excellent hygiene to minimise the risk of grain contamination.

Specialist grain-storage sheds can be constructed to make filling and unloading simpler. Consider aeration requirements and sealing methods for fumigations early in the design phase.

Sheds and bunkers are most useful as a short-term storage solution to assist harvest logistics. They can be a useful component of an on-farm grain storage system that incorporates other gas-tight sealable grain storage facilities.

Capital investment

The cost of grain storage in sheds varies widely depending on footing and slab requirements as determined by soil type. Bunkers are arguably one of the lowest capital cost storage options but will require more labour and equipment for out-loading. Method of construction and alternative uses can also vary the cost of construction. Bunker sizing can vary according to the use of walls and tarpaulin selection. Bunker tarp manufacturers can provide a guide as to the most economical dimensions and material choices.

Aeration cooling

Aerating grain stored in a shed is difficult due to the variation in grain depth. Specialised suppliers can set up aeration systems for sheds, which usually involve ducting in sections that can be removed as the shed is emptied to allow loader access.

Pest and insect control

Given the open nature of most sheds on-farm, pest and insect control presents some challenges. Fumigation with gas-proof sheeting placed over the stack is difficult to seal. Bulk handlers, including CBH in Western Australia, have invested heavily in sealing gas-tight bulk storage sheds to permit fumigation. Protectants are available in the eastern states of Australia (and some in Western Australia) to assist pest prevention in cereal grains but buyers should be consulted before applying any products to grain. Mice, birds and other vermin can also be a challenge to control around sheds and bunkers.

Photo 7: *The success of a bunker relies on careful site selection and preparation, quality tarps and equipment for managing tarps and out-loading. (Source: GRDC)*

Loading and unloading

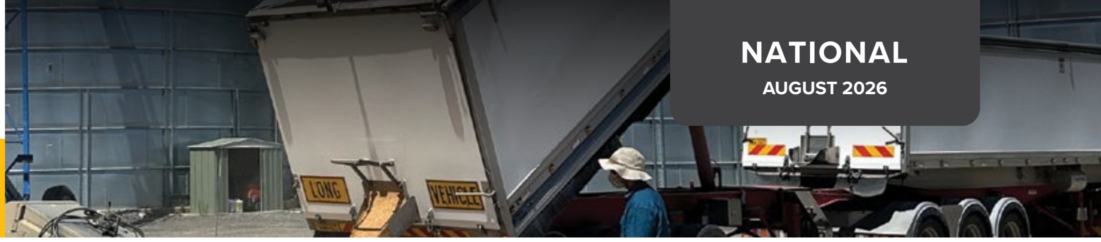
One of the biggest drawbacks of sheds used for grain storage is the difficulty getting grain in and out. Using an auger or belt conveyor to fill the shed from the truck is common practice.

For out-loading sheds and bunkers, some operators opt for bulk-handling buckets on front-end-loaders or telehandlers to fill direct into trucks or large hoppers mounted over an auger or conveyor. Some grain trade operators use this approach to minimise grain damage when handling grains prone to splitting, such as legumes.

Grain vacuums can also be used to out-load grain from sheds. Regardless of the out-loading options, inevitably, a final clean is performed with a broom and grain shovel, which can take time if hygiene is to be maintained.

1.1.4 Underground pits

Photo 8: *Grain storage pits can be used in some soil types as a low cost form of storage for low-value or off-specification grain. They can be lined or unlined but are typically cut in a long narrow trench with an excavator or telehandler. (Source: Richard Quigley.)*



Underground pits can be an effective, low-cost method of storing grain for the long-term. Pit storages are most commonly used on farm for storing drought feed reserves. Feed grain has been recovered in good condition after more than 10 years.

Pits can be unloaded using the same excavator or telehandler that was used to dig them out.

Size and construction

Careful preparation is essential for underground storage to be successful.

Locate the pit on a well-drained site above the water table, with the immediate surrounds graded to prevent rainfall run-off collecting in the pit area. If constructing multiple pits, leave at least 10 metres between pits to prevent seepage from an empty pit into a full pit.

Keep each storage pit no more than three metres wide to allow the covering soil to be placed and removed by a telehandler without having to drive close to the edge of the pit. The depth will be determined by the unloading facilities.

Match pit capacity to available silo and truck capacity so the pit can be completely emptied after it is opened.

A pit may be unlined if the floor and walls can be made firm and clean. Plastic lining is often used and should be laid at the starting end just before loading starts.

The lining can be unrolled as filling progresses. Fill the pit until the grain forms a slight ridge along the centre. A layer of plastic placed over the ridged pit and extending at least 1.5 m beyond each side should be carefully covered with the excavated soil. This helps shed water away from the grain.

Loading

Grain moisture content must be less than 12% to reduce the risk of spoilage.

SAFETY TIP

Filling can be carried out either by driving into the pit or by using an auger from the side. Avoid driving too close to the pit edge. Keep heavy machinery, including trucks and tractors, at least one pit depth back from the edge to minimise the risk of collapse.

After filling a pit, cover the grain with plastic sheeting and soil. A layer of soil about 0.5 metres thick will provide adequate protection from weather and pests. An initial layer of sand will prevent rocks or hard clods from damaging the top cover. Shape the soil to facilitate run-off. Mark the location of the pit with a peg at each corner.

Pest and insect control in pits

A well-constructed pit storage is assumed to be air-tight and oxygen levels gradually reduce over time. The low oxygen levels prevent development of damaging numbers of grain insects. If in doubt about the gas-tightness of the pit, grain protectants can be applied to cereal grain when it is placed in storage to prevent insect pests at least for the first few months of storage.

Unloading

To unload the pit, it is necessary to be able to remove all the covering soil without contaminating the grain. This can be difficult and is the reason for using narrow pits.

Always unload the entire contents once the pit is open, otherwise losses due to drainage problems are likely.

Grain vacuum machines can be useful for emptying pit storages, and allow much easier final clean-up of grain than other methods. Mobile augers or belt conveyors with fixed and guarded cross-sweeps, or a front-end loader can be used to empty the pit.

MORE INFORMATION

DAF QLD note Grain Storage — Underground pit storage of grain

DPIRD Farmnote Stored grain management: Underground storage of grain

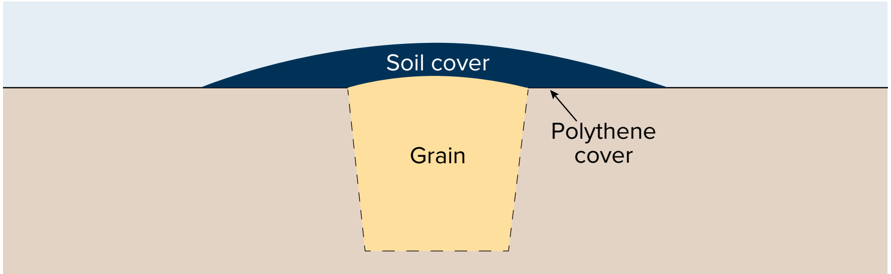


Figure 2: *Cross section of underground grain storage pit*
Source DPIRD

1.2 Grain storage considerations

When investing in and planning a grain-storage facility there is a range of factors to consider, regardless of the storage type.

1.2.1 Access for in-loading and out-loading

Continuous loop roads around the grain-storage facility requiring minimal, or no, reversing are ideal and can dramatically improve loading and out-loading efficiency while minimising damage to equipment through accidental collision.

Dedicate sufficient hardstand area to allow auger or grain conveyor access and the efficient movement of grain loads.

Where steeper slopes exist, some growers have terraced the slope with a retaining wall, to allow them to reduce the lift height (and auger size) for loading the silo.

Where retaining walls exceed 1 m in height, consider guard rails and access steps.

1.2.2 Proximity to resources (power sources — electricity and fuel)

Whether the facility is to be powered for aeration, i.e. using diesel or electricity, consider the proximity to these resources, particularly if the facility will be built in stages as each stage becomes affordable.

Connection to mains power can be expensive depending on the distance to the line. Some large fans also require three-phase power which requires a specific pole transformer.

With augers, machinery and tipping trucks in use around the facility, placing power underground is expensive, but can significantly improve safety.

It is worth considering fuel sources and fuel lines for dryer installations, or future dryer installations, when planning the facility layout and constructing the pad.

SAFETY TIP

1.2.3 Health and safety considerations

Operational safety considerations should be key to the facility design. Allow plenty of space for auger transport and movement around the facility.

Ensure overhead power-lines are located nowhere near the pad where augers, conveyors or trucks might be operating — ideally locate power underground. As a minimum, have signs and markers installed to alert operators to overhead powerlines.

Construct pads that are flat, hard-packed stands, which allow tipping trucks to elevate without risk of toppling over sideways.

Minimise any slopes and ensure they are of a constant grade. Position drainage lines and holes away from high-traffic areas to reduce the risk of equipment falling through, while maximising drainage effectiveness. Incorporate residual current devices (RCDs) into electrical switchboards to prevent electrical shock if, for example, an electrical cable was accidentally cut. A qualified technician is required to carry out any 240-volt electrical work. They will ensure the components are safe to use in areas where combustible dusts are present.

For more information on silo safety, see Section 3 Safety around grain storage.

1.2.4 Road access

The ability to get trucks in and around the grain-storage facility is paramount to its success. Sealed or hard, all-weather roads to the site from a main road are essential for year-round out-loading, which will ensure grain sale contracts are met in a timely manner and can deliver marketing advantages.

1.2.5 Proximity to trees and insect or bird havens

Avoid locating storage facilities near trees, haystacks and haysheds — all are havens for insects and birds, making migration from nature to the grain stored in the facility easier. Similarly, water sources are attractions for vermin and birds. Avoid water sources when selecting a site for a grain storage facility.

1.2.6 Proximity to harvest locations

One of the most important considerations of facility placement and layout is harvest logistics to make the busiest time of use most efficient.

While placing silos close to a house or existing infrastructure is most common, it may not be the most efficient placement from a logistics perspective. Ultimately the location will be a balance between harvest efficiency, proximity to power access but away from houses to reduce dust and noise from aeration fans running all hours.

1.2.7 Determining storage capacity requirements

Calculating 'adequate storage capacity' can involve an enormous range of variables. Consider what would be the 'ultimate' in on-farm storage capacity for the farm and then plan a series of stages to achieve this ultimate goal.

For some growers, ultimate storage capacity is 100 per cent of their harvest, while others will always use an external bulk handling system to some extent. This is likely to vary between state bulk handling operators, dominant crop types, target markets and distance from the farm to bulk handlers.

As an initial step, aim for a reasonable proportion of the total harvest and plan to expand the facility from there. Consider investing in a number of small silos as the first step and buy larger silos as the business expands.

Smaller silos, for example around 70 to 100 tonnes, will always be valuable for segregation and blending or insect control in small parcels of grain.

Commonly, a variation of storage sizes and types provides flexibility – cone silos for segregation, pulses and multiple fills per season for harvest logistics; large flat-bottoms for efficient cereal storage; temporary large flat-bottoms for efficiency, temporary storage for extra capacity when needed.

1.2.8 Determining out-loading throughput rates

A typical out-loading rate is around 3-4 t/min. Higher out-loading rates can reduce truck turnaround times and improve freight efficiency.

1.2.9 Weighbridges

With fines for overloading increasing in severity and occurrence in most states, using a weighbridge could pay for itself quickly. Weighbridges can be incorporated into the silo load-and-unload loop with effective installations providing readouts for the driver when approaching from both sides. The alternative but not as reliable option is using truck airbag readings.

Photo 9: *The addition of a weighbridge can help maximise truck carrying efficiency and avoid overloading fines. (Source: Ben White, Kondinin Group)*

1.2.10 Blending abilities

The ability to blend grains and optimise specifications is one of the primary benefits of an on-farm storage facility. The ease of out-loading for blending is greatly improved by adding a belt or drag-chain grain conveyor and elevator system to the facility. This addition also requires remotely operated silo outlets, a seal-off system to isolate silos when they require fumigation and a method for cleaning the conveyor system to maintain meticulous hygiene.

1.2.11 Sampling abilities

Keeping a record and sample of grain stored on-farm can be useful for subsequent testing and quality assurance.

Owners of larger on-farm, grain-storage facilities commonly add a sampling shed where grain-quality specifications are collected and stored. Taking the sample from silos can be easier if sealable sample ports can be safely accessed from ladder or stair platforms, to obtain a cross section of the stored product. Truck sampling options include push spears and vacuum spears, which are designed to take a profile section of the load. Collecting running samples during loading is another option providing a full cross section of the grain flow is collected.

SAFETY TIP

If adding an elevated platform to the facility, remember to add compliant handrails and stairs to minimise the risk of falling.

1.2.12 Cleaning and facility maintenance

Maintaining thorough site hygiene is easier with a quality hard surface. Concrete pads are essential for silos to sit on but extended aprons can also assist cleaning grain spilt during loading and unloading.

Common grain trap points include dump-pits, drainage or aeration channels and around silo bases.

Clean all grain off the site on a regular basis to avoid harbouring insects, which may infest stored grain. Ensure a water point is accessible for washing out cone-bottom silos after they are emptied. Grain vacuums are popular with owners of flat-bottom silos to remove residual grain where sweep augers have not been able to reach.

For more information on grain storage hygiene, see Section 5 Hygiene and structural treatments.

1.2.13 Facility earthworks

When determining earthworks requirements, allow sufficient space around the pad for construction vehicle access and manoeuvring. Raised pads are the most common design, as they minimise the risk of water damage to both the storage facility and the stored grain. Pad height will vary depending on the site's topography and drainage, but elevations of around 500 mm above the surrounding ground level are common.

Soil type impacts

Soil type can have a huge bearing on silo foundation design and requirements for facility earthworks. Foundations are normally engineered with depth of footing and reinforcing determined according to the physical properties of the soil. Highly-reactive soils shrink and swell according to their level of moisture and typically require additional foundation engineering and reinforcing, which comes at a greater cost. As a rule of thumb, experienced silo-pad concreters assume soil type according to region for quoting purposes with slight variations dependent upon on-site requirements.

Drainage

In addition to maintaining a raised, firm pad for the storage facility, plan for drainage to handle and direct run-off away from the pad. In some cases the natural topography of the site may assist free drainage while on flat sites, drainage channels may have to be formed to carry water away from the site. A well-designed pad for transportable cone-bottom silos will ensure water does not pool near the base structure, which can quickly rust out.

1.2.14 Lighting

Loading and out-loading is often carried out at night during harvest and effective lighting not only makes the job easier for drivers but also improves safety at the site.

Efficient and robust forms of lighting, including LED, are suitable choices for short-throw requirements.

If laying electrical cables underground, for aeration or auger drives, consider laying electrical cables for lighting at the same time.

1.2.15 Communications

With numerous market opportunities and volumes of information and data detailing specifications of stored grain increasing, facilities for data transfer and communication add value to any site plan, particularly if the site is to be equipped with a sampling and testing shed. Satellite options for example, Starlink can provide reliable access in fringe areas.

1.2.16 Planning to expand

It is uncommon for a grower to build a complete on-farm grain storage system in a single stage. The capital investment required is substantial and, in most cases, storage infrastructure expands progressively as farm productivity and storage requirements increase.

Planning for staged development helps ensure key elements of the overall site design are incorporated from the outset. It can also reduce future costs by coordinating the installation of underground services, electrical infrastructure and concrete pads.

The simplest expansion option is to extend an existing row of silos. Alternative layouts, such as circular arrangements with a central receival and out-loading point, may offer operational advantages.

Linear layouts allow a single out-loading conveyor to feed an elevator for truck loading or grain transfer between silos.

Future expansion should also consider grain drying requirements, including provision for batch dryers or dedicated drying silos with adequate airflow capacity.

Allow for the future installation of aeration controllers, electrical services and communications infrastructure where required.

1.2.17 Staking out the facility

Everything can look good on plans, but it is important to physically stake out the site of grain facilities to ensure proportions have not been underestimated or overlooked. Driving pegs onto the site to indicate silo placement, pad borders and the positioning of roads and weighbridges can help visualise the suitability of the plan for the site.

1.2.18 Adapting existing facilities

In many cases, existing infrastructure is worked into the design.

Upgrading, including retro-sealing silos and sheds, can be an option to reduce the overall cost of storage per tonne, but remember retro-sealing is only useful if it passes the Australian Standard 2628 half-life pressure-test. Also budget for ongoing maintenance costs for retro-sealed facilities.

New rows of silos can be offset from existing rows to improve access and out-loading efficiency while accommodating older storage infrastructure.

The first upgrade to older silos should be the installation of appropriately sized aeration fans and ducting.

1.2.19 On-site office and sampling sheds

An on-site office is ideal for keeping records and samples of stored grain. It can house expensive, sensitive testing equipment and be used as a crib-room for drivers and employees.

Portable site offices are a common choice as they can be fitted with air-conditioning and are often pre-wired for electrical outlets. Used site offices regularly come up for sale on mining sites and can be bought at a fraction of the new price.

As a minimal alternative, an on-site cabinet for load documentation and records will ensure hard copies of silo contents and load specification details are kept safely on site.

MORE INFORMATION

Smart Storage Setups (Kondinin Group 2021)

Slick Storage Setups (Kondinin Group 2013)

1.2.20 Dump pits

Dump pits can be installed in combination with paddle or drag conveyors to quickly and easily take and elevate grain to load storages.

Carefully cover dump pits when not in use to keep water out and keep pits and surrounding areas clean to minimise contamination and spoilt grain. Easy cleaning is a key consideration to avoid cross contamination and grain trap points to harbour insects.

1.2.21 Conveyor types

Numerous options for shifting grain around the site are available and each has benefits and disadvantages.

Maximum angles of elevation vary between conveyors according to grain but figures are usually quoted for wheat.

Augers can occasionally damage grains that are prone to splitting, particularly older augers with worn flighting. Belt conveyors are the second most commonly used method of grain transfer and are often preferred when handling grains susceptible to damage.

As transportable units, belt conveyors are generally limited to operating at or below the grain's angle of repose.

The angle of repose is the maximum angle, measured from the horizontal, at which grain will naturally form a stable pile. It varies between grain types and is an important consideration when selecting and operating belt conveyors.

As an example, the angle of repose for wheat is 27 degrees while canola is 22 degrees. Flow rates reduce as the angle of elevation increases to approach the repose angle. Belts are often cupped along the conveyor length to accommodate grain and hygiene is excellent with the design of a belted conveyor being self-cleaning.

Bucket elevators are predominantly used to elevate grain vertically and are commonly used together with belted conveyors transferring grain horizontally, or splitters diverting grain down chutes through a gated manifold.

Bucket elevators are self-cleaning by design and are typically fixed position equipment.

Drag-chain conveyors or paddle conveyors use a series of paddles fixed to a loop of chain moving inside a conduit. Drag chains can elevate at any angle, including horizontal, and are largely self-cleaning, although corners of the chain-loop will normally require attention. Drag-chain conveyors are a permanent installation but are extendable for facility expansion.

MORE INFORMATION

[On farm grain storage benefits analysis]

Economics of on-farm storage

As the use of on-farm grain storage across Australia expands, the question of economic viability gains significance.

There are many examples of growers investing in on-farm grain storage and paying for it in one or two years because they struck the market at the right time, but these examples are not enough to justify greater expansion of on-farm grain storage.

Analysis by Pinion Advisory found that post-harvest grain price movements are highly variable and difficult to predict. In most cases, the value of on-farm grain storage depends on the individual farming business, with the key drivers varying according to location, harvest logistics, grain quality and marketing opportunities. A link to the full report is provided opposite.

For most growers, the greatest return from on-farm storage comes from combining multiple benefits rather than relying on seasonal price movements alone. These may include improving harvest logistics, segregating or blending grain to capture quality premiums, increasing marketing flexibility, and delivering grain directly to buyers to reduce freight and handling costs.

To make a sound financial decision, compare the expected returns from grain storage vs expected returns from other farm business investments, such as more land, more harvest equipment, wider machinery, more trucks or paying off debt. Calculating the costs and benefits of on-farm storage enables a return on investment (ROI) figure, which can be compared with other investment choices.

Use the *Grain storage cost–benefit analysis template* (Table 1) to compare different storage types or varying storage scenarios.

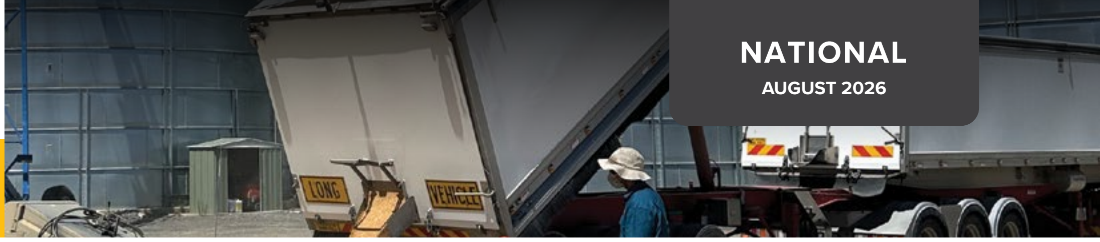
The key to a useful cost–benefit analysis is identifying which financial benefits to plan for and costing an appropriate storage to suit that plan. If the plan includes the potential to store grain for longer periods, a gas-tight sealable storage option should be considered to enable fumigation.

When considering temporary storage types for shorter term storage, give thought to the business' labour availability to fill, manage and empty those storages.

Being realistic about your attentiveness to detail when it comes to setting up and managing temporary storages meticulously could avoid an inevitable disaster of damaged grain.

A combination of storage types often works well. Cost each component individually before combining the results to calculate the overall return on investment for the proposed system. To compare costs and benefits consistently, convert all figures to a dollars-per-tonne ($/t) basis.

When comparing manufacturer-quoted storage capacities, check that the grain bulk density used is consistent with the grain you intend to store. It is also important to reality-check the figures throughout the calculation process to ensure they are realistic.



MORE INFORMATION

Grain storage cost considerations report

Table 1: *Silo capital costs by region (2026)*

Western GRDC region nominal storage investment costs	Average cost/t	Range min cost/t	Range max cost/t
Transportable silos (50 t to 150 t capacity)	$220	$183	$266
Build-on-site cone-bottom silos (150 t to 500 t)	$347	$188	$565
Large flat-bottom silos (500 t to 4000 t)	$226	$179	$325
Northern GRDC region nominal storage investment costs	**Average cost/t**	**Range min cost/t**	**Range max cost/t**
Transportable silos (50 t to 150 t capacity)	$320	$228	$458
Build-on-site cone-bottom silos (150 t to 500 t)	$332	$188	$448
Large flat-bottom silos (500 t to 4000 t)	$219	$160	$295
Southern GRDC region nominal storage investment costs	**Average cost/t**	**Range min cost/t**	**Range max cost/t**
Transportable silos (50 t to 150 t capacity)	$319	$228	$458
Build-on-site cone-bottom silos (150 t to 500 t)	$313	$188	$448
Large flat-bottom silos (500 t to 4000 t)	$204	$158	$275

Source: GRDC Grain storage extension team 2026

Table 2: *Shed, bunker and bag capital costs*

Nationally	2000 t Average cost/t	6000 t Average cost/t	10,000 t Average cost/t
Sheds (2000 t to 10,000 t)	$169	$144	$119
Nationally	**500 t Average cost/t**	**1000 t Average cost/t**	**2000 t Average cost/t**
Bunkers (500 t to 2,000 t)	$13.15	$9.85	$7.60
Nationally	**200-550 t Average cost/t**		
Grain bags	$5.39		

Source: GRDC Grain storage extension team 2026

Capital costs shown in tables 1 and 2 were sourced from a wide range of manufacturers, suppliers and grower quotes or invoices. They are a guide only and accurate at the time of printing. To view the full report follow the QR code link on this page.

A number of positions and assumptions for specific variables have been made in calculating the cost of grain storage investment as follows:

- All prices exclude GST
- All prices exclude freight
- All capacities quoted are for wheat including a compaction allowance of 5%
- Shed prices assume the shed is filled to capacity unless discounted for average fill
- Silos priced are all gas-tight sealable meeting AS2628
- Ladders are an essential management tool and have been included in pricing
- Silo pricing excludes earthworks, electrical and plumbing specific to a site
- A linkage and PTO tractor is available for grain storage bag machinery

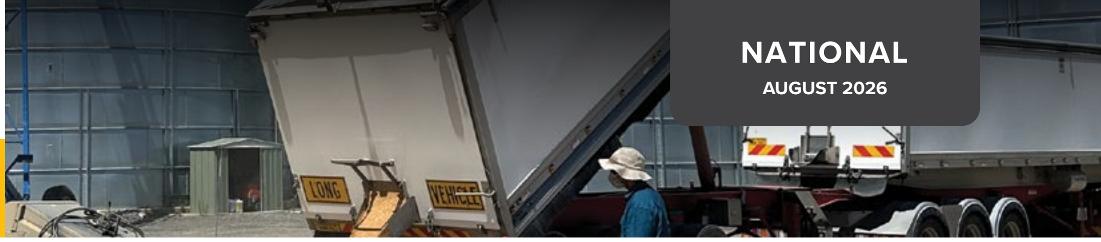
MORE INFORMATION

Economics of grain storage

Table 3: *Grain storage cost-benefit analysis template*

	Financial gains from storage		Example ($/t)
A	Harvest logistics/ timeliness	Grain price x reduction in value after damage % x probability of damage %	32.50
B	Local market gain (feed to feedlot)	Post harvest grain price – harvest grain price	20.00
C	Freight (peak vs out-of-season rate)	Peak rate $/t – post harvest rate $/t	10.00
D	Cleaning to improve the grade	Clean grain price – original grain price – cleaning costs – shrinkage	
E	Blending to lift average grade	Blended price – ((low grade price x %mix) + (high grade price x %mix))	
F	Drying for early harvest	Grain price x reduction in value after damage % x probability of damage %	
G	Other benefits		
H	**Total benefits**	Sum of benefits	61.50
I	Capital cost	Infrastructure cost ÷ storage capacity	250.00
	Fixed costs		
J	Annualised depreciation cost	Capital cost $/t ÷ expected life of storage eg 30 yrs	8.33
K	Opportunity cost on capital	Capital cost $/t x opportunity or interest rate eg 6% ÷ 2	7.50
L	Insurance cost	Capital cost x 0.3%	0.75
M	**Total fixed costs**	Sum of fixed costs	16.58
	Variable costs		
N	Storage hygiene	(Labour rate $/hr x time to clean hrs ÷ storage capacity) + structural treatment	0.10
O	Aeration cooling	Indicatively 50c for the first month then 20c per month/t	1.18
P	Repairs and maintenance	Estimate eg. capital cost $/t x 0.25%	0.56
Q	Inload/out-load time and fuel	Labour rate $/hr ÷ 60 minutes ÷ auger rate t/m x 3	1.13
R	Time to monitor and manage	Labour rate $/hr x total time to manage hrs ÷ storage capacity	0.09
S	Opportunity cost of stored grain	Grain price x opportunity or interest rate eg 6% ÷ 12 months x No. months stored	10.50
T	Insect treatment cost	Treatment cost $/t x No. of treatments	0.40
U	Cost of bags or bunker tarp	Price of bag ÷ bag capacity tonne	
V	Shrinkage (spilt/lost grain)	Grain price $/t x percentage lost eg 0.2%	
W	Drying costs (optional)	Total drying costs ÷ total tonne dried	
X	**Total variable costs**	Sum of variable costs	14.02
Y	**Total cost of storage**	Total fixed costs + total variable costs	30.60
Z	**Profit/Loss on storage**	Total benefits - total costs of storage	30.90
	Return on investment	Profit or loss ÷ capital cost x 100	12.4%
	Payback period years	Capital cost ÷ profit or loss on storage	9 years

Grain storage cost–benefit analysis template
(Source: GRDC Economics of on-farm grain storage)



2.1 Calculating the costs — key considerations

The following colour-coded letters and text correspond to each of the coloured lines in the Grain storage cost -benefit analysis template (Table 3).

The following examples are not necessarily all related to the same situation.

When entering percentage figures into a calculator, first divide by 100. For example, enter 35% into the calculator as 0.35 and enter 5% as 0.05.

When carrying out calculations with multiple operations (for example x, ÷, +, - and brackets) follow ‘BOMDAS’ which is an acronym for ‘brackets, orders, multiplication, division, addition, subtraction’. This means calculate anything in brackets first, then calculate orders then multiplication then division then addition then subtraction. If unsure, follow an example to check you get the same answer.

2.1.1 Financial benefits

A Harvest logistics

One financial benefit almost every grower can gain from on-farm storage is improved harvest logistics or timeliness — aiming to reduce the amount of time the harvester is stopped because trucks can’t keep up carting the grain away.

If this is the case, ensure the planned grain storage has capacity for fast and efficient in-loading during harvest. The probability part of the calculation refers to how often a weather event damages grain. For example if rain damages ripe crops on average four times every 10 years then the probability is 40%.

Market opportunity can provide a return for storing grain to sell after harvest. In the short term, storing on-farm might give time to market the grain to the best receival site.

B Local market

If you are aiming for a local market, such as a feedlot or dairy, consider the length of time you are likely to need to store the grain and what premium the local market is likely to pay for storage (if any).

Whether aiming for a seasonal price trend or a local market trend, the benefit calculation is the same.

VIDEOS

On-farm storage in the SA Mallee with Corey Blacksell

A CALCULATION

Grain price x reduction in value after weather damage x probability of weather damage %.

Example:
$350/t x 30% x 30% = $31.50/t

B CALCULATION

Post-harvest grain price – harvest grain price

Example: $370/t – $350/t = $20/t

MORE INFORMATION

GRDC Ground Cover Case Study: Storage smooths the harvest and quality control

CALCULATION (C)

To local site: peak freight rate – post-harvest freight rate

Example to local site:
$25/t - $15/t = $10/t

Or

To port: port price – freight farm to port post harvest – local receival price + freight farm to local site at harvest

Example to port: $372/t – $25/t – $340/t + $18/t = $25/t

CALCULATION (D)

Cleaner cost: (depreciation + opportunity cost of capital + repairs and maintenance) ÷ average throughput tonnes per year + fuel + labour.

Example of own cleaner costs:
($1000 + $100 + $400) ÷ 800 t + $0.30 + $3.00 = $6.30/t

Cleaning benefit: clean grain price – original grain price – cleaning costs – shrinkage

Example of cleaning benefit:
$340/t – $300/t – $6.30/t – ($300/t x 5%) = $18.70/t

Photo 1: *A planned approach to grain storage greatly increases the chance of making money out of it, rather than hoping for the best and expecting it to be profitable. (Source: Chris Warrick, Primary Business)*

C Freight

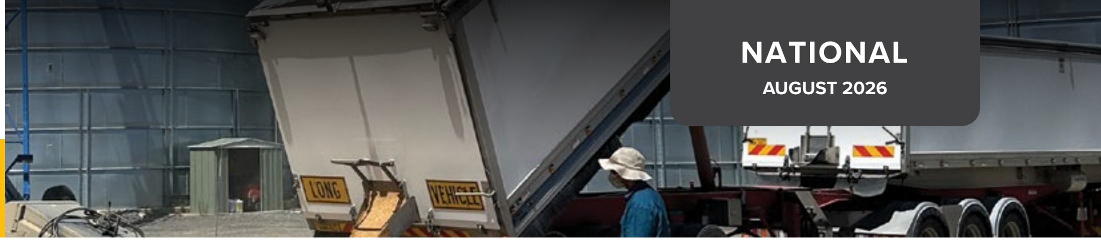
In some regions, freight at harvest is charged at a premium due to high demand and long queues at receival sites. Holding grain on farm to cart after harvest can create a financial benefit by getting cheaper freight rates to the local receival site, or having time to cart directly to port and bypass local bulk handler charges.

D Cleaning

Having access to a grain cleaner can achieve benefits if it means you can meet the criteria of a higher grade. In most cases, this involves storing grain on farm to clean after harvest, or on a wet day, when the pressure is off.

The calculation requires a cleaning cost, which can be based on a contract rate or by totalling the cost of owning and running a cleaner.

The example opposite demonstrates one way to calculate the cost of using your own cleaner.



E CALCULATION

Blended price – ((low grade price x % of mix) + (high grade price x % of mix))

Example:
$320/t – (($300/t x 70%) + (340 x 30%)) = $8/t

F CALCULATION

Grain price x reduction in value after weather damage x probability of damage.

Example:
$340 x 30% x 20% = $20.40/t

E Blending

In some cases, grain of varying qualities can be blended to lift the overall grade. This can provide a financial benefit if a small portion of higher-grade grain can be blended to lift the larger portion of lower-grade grain and the price difference for the grade is significant.

F Drying

Where grain drying facilities are available grain can be harvested earlier in the season or harvesting can start earlier each day and extend later each evening. This can potentially lead to a financial benefit if more grain can be harvested and stored to reduce the amount lost from a weather event during harvest. Practically there is a limit to the volume of grain that can be harvested early or at higher moisture content, so the benefit may only apply to a portion of the storage facility's total capacity.

If using drying for early harvest in your calculation, remember to include the cost of drying the grain and include aeration cooling and drying in the capital cost.

The probability part of the calculation refers to how often a weather event damages grain. For example if rain damages ripe crops on average twice every 10 years then the probability is 20%.

G Other benefits

In addition to the benefits already covered, there may be location-specific benefits or opportunities to value-add to grain after storing it on farm.

One example of limited quantity would be stored planting seed, the benefit being the difference in the price to buy in seed less the price grain could be sold for at harvest, less cleaning and treatment costs.

Calculate any other benefits in the same way; on a dollar-per-tonne basis and remember to account for any associated fixed or variable costs.

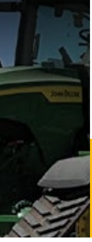
H Total benefits

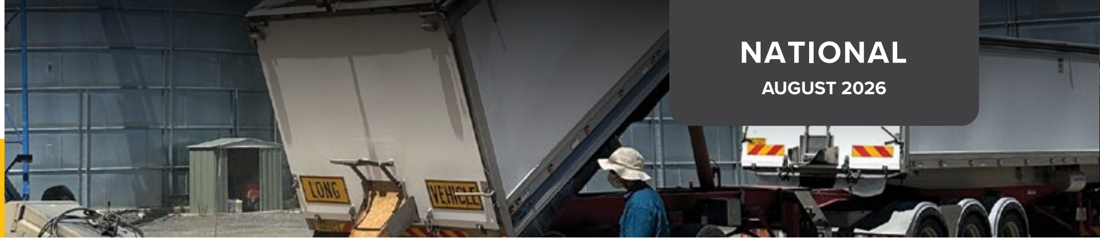
In many cases, it is worth aiming for more than one benefit to make storage pay.

For example, relying on seasonal market trends alone in many cases won't cover the costs of storage, but when combined with avoiding peak freight rates it might be feasible.

At the same time, it would be unrealistic to expect to get all the possible benefits in any one year.

Select the most locally relevant and reliable benefits for your operation and add them up to get the total benefit in dollars per tonne.





2.1.2 Fixed costs of on-farm storage

The costs of grain storage can be allocated into two groups — *fixed costs* and *variable costs*.

Fixed costs don't vary from year to year and are the same whether the storage is used or not.

It is important to match the storage type to the storage plan. For example, if you are planning to hold grain for several months to capture a market trend, ensure you can control insects and maintain grain quality during that period. If phosphine or another fumigant is part of your insect control strategy, a gas-tight sealable storage is required.

I Capital cost

To determine the fixed costs of storage, first calculate the capital cost — all the infrastructure, site works, concrete, equipment and labour to set up the storage. Remember to include augers or conveyors for loading and unloading as well as aeration cooling systems and electrical work if planned to be part of the build.

Divide the capital costs by the storage capacity to give a capital cost per tonne.

In the case of grain bags and bunkers, the capital costs are significantly less as they consist of the in-loading and out-loading machines, permanent site works and any other associated equipment required.

Always match the storage type with the storage plan.

For storages that can be used multiple times per year, such as silos used for winter and summer crops, or filled twice a season to aid harvest logistics, the fixed costs per tonne can be halved because the cost is spread over twice the volume of grain each year.

The most significant fixed costs for grain bags are the in-loading and out-loading machines, so the more grain they are used to store each year, the lower the fixed costs on a per tonne basis.

If there is not a lot of grain to store in bags, consider reducing the capital cost by owning half the machinery in partnership with a neighbour, or hiring the machinery so it becomes a variable cost.

I CALCULATION

Infrastructure costs ÷ storage capacity

Example for silos: (Flat-bottom silos, ground works and aeration $1,300,000 + auger $200,000)÷ storage capacity 6000 t = $250/t

Example for grain bags: (in-loading machine $50,000 + out-loading machine $80,000 + permanent site preparation $2000) ÷ storage capacity 1500 t = $88/t

J Depreciation

After establishing the capital costs, the first fixed cost — depreciation — can be determined.

Annualised depreciation is the capital cost spread across the expected life of the storage. The expected life of a storage is the period of time during which it will function reliably without needing major repairs.

For gas-tight silos the estimate is 30 years, for machinery it would be less and will depend on the usage.

J CALCULATION

Capital cost ÷ expected life of the storage or inload and out-loading machines

Example for silos:
$250/t ÷ 30 years = $8.33

Example for grain bags:
$88/t ÷ 15 years = $5.86/t

K Opportunity cost on capital

Opportunity cost on capital is an allowance for what the capital could be earning or saving if it was used elsewhere.

If an alternative use of the funds is to invest in the share market you might use 10–15%, but if the alternative is to pay off debt then you might use the finance interest rate.

Divide the opportunity cost by two to account for the fact that the storage will hopefully be paid off over time, so the interest payable will also reduce over time. Remember to use the same opportunity cost rate and method between the various investments being compared.

K CALCULATION

Capital cost x opportunity cost or interest rate ÷ 2

Example for silos:
$250/t x 6% ÷ 2 = $7.50

Example for grain bags:
$88/t x 6% ÷ 2 = $2.64/t

L Insurance on infrastructure

Insurance is estimated at around 0.3% of the capital cost of the infrastructure.

M Total fixed costs

The annualised depreciation and the opportunity cost of capital added together give the total fixed costs of storage. This is the cost of on-farm storage every year before it is even used. It is the cost of the privilege of having storage on site whether it's used or not.

Photo 2: *Bunkers may have lower fixed costs than other storage options but often have higher variable costs and limited flexibility. (Source: Chris Warrick, Primary Business)*

2.1.3 Variable costs of on-farm storage

Costs that vary by the amount of grain stored each year or by how long grain is held in storage are *variable costs*.

Some variable costs vary according to the type of storage used, while others will be the same for any storage type. For example, in-load and out-load time as well as shrinkage will be different for a cone-bottom silo compared with a bunker that requires tarps and a front-end loader.

Time to monitor and manage will be different for a silo compared with grain bags, which require more frequent checking and patching.

Always be realistic with calculations. If planning to store grain in bags for a few months and deliver the same quality grain, include enough time to check and repair the bags at least weekly.

The opportunity cost of stored grain on the other hand will be the same for any storage type if the grain is held for the same length of time, including if comparing to using a bulk handler or contract storage facility.

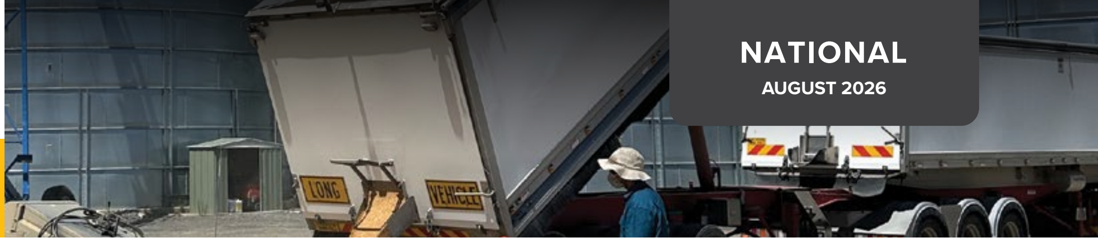
N Hygiene

Storage hygiene is a minor cost relative to other costs. However, it is worth calculating to highlight how little extra it costs for such a significant benefit in having a pest-free storage to start with and not having grain laying around that attracts pests to the site. For more information on storage hygiene, see Section 5 Hygiene and structural treatments.

N CALCULATION

(labour rate x time to clean ÷ storage capacity) + structural treatment cost

Example:
($45/hr x 5hrs ÷ 3,000 t) + $0.02/t = $0.10/t



O CALCULATION

Fan motor size x electricity cost x run time ÷ storage capacity

Example: 0.5 kW x $0.30/kWh x (120 hrs + 84 hrs + (100 hrs/month x 5 months) ÷ 80 t = $1.18/t

P CALCULATION

Capital cost x 0.25%

Example:
$250/t x 0.25% = $0.63

Q CALCULATION

Labour rate ÷ 60 minutes ÷ auger rate x 3

Example:
$45/hr ÷ 60 minutes ÷ 2 t/min x 3 = $1.13/t

R CALCULATION

Labour rate x total time to manage ÷ storage capacity

Example:
$45/hr x 1 hr per month x 6 months ÷ 3000 t = $0.09

VIDEOS

On-farm Grain Storage: Economics of aeration

O Aeration cooling

Aeration cooling is another variable cost that is trivial in the economic outcome of storing grain, but has a significant effect on grain quality and insect activity. This calculation highlights how little it costs for a substantial benefit. Indicatively, aeration cooling fans delivering 2-3 litres per second per tonne will cost about $0.50/t for the first month in storage while the grain temperature is reduced, then $0.20/t per month to maintain a cool grain temperature. This is based on an automatic aeration controller running the fans continuously for the first five days, then 12 hours per day for seven days, then 100 hours per month for maintenance. An example calculation is shown opposite, but the indicative cost of $0.50/t plus $0.20/t/month is accurate enough for most scenarios.

If a generator is used to power aeration fans, add the purchase and installation to the capital costs at 'J' and use the following formula to calculate running costs. Fuel consumption (L/hr) x fuel price ($/L) x run time (hrs) / storage capacity (t).

For more information on aeration cooling during storage, see Section 5.4 Aeration cooling for pest and quality control.

P Repairs and maintenance

Repairs and maintenance vary with each storage type. Grain bags require in-loading and out-loading machines to be maintained, silos require seals to be maintained to ensure they remain gas-tight sealable, bunkers require repairs to tarps and walls and augers take a small amount of upkeep to increase their working life.

If storage facilities already exist, check financial records to find repairs and maintenance costs on average each year, otherwise use a percentage of capital cost to estimate an allowance.

As with hygiene, maintenance is a relatively small cost with significant benefits, enabling smooth operation and maintaining grain quality.

Q In-loading and out-loading

In-load and out-load time accounts for the labour required to fill and empty the storage. There is a tendency for growers to overlook the cost of time, but it needs to be accounted for because it is time that could be used to earn money doing something else.

As a minimum, use a labour rate that would be required to pay a worker to do the job at that time of the year. If you know how long it takes to fill and empty the storage then simply divide that time by the storage capacity and multiply it by the labour rate.

The calculation shown is one way to estimate the time and associated cost, accounting for time to fill and empty with the auger as well as time to line up the truck.

R Monitoring and management

The time to monitor and manage grain in storage varies with the type of storage and length of time grain is stored.

Grain in silos requires fortnightly monitoring during the warmer months and monthly monitoring during the cooler seasons to ensure issues are dealt with quickly to keep damage to a minimum.

Grain stored in bags or bunkers needs to be monitored more frequently. There is a higher risk of holes forming and exposing grain to water, leading to mould growth and insect infestation.

Monitoring is another relatively small cost, but has potentially disastrous consequences if not carried out regularly.

S Opportunity cost of stored grain

The opportunity cost of stored grain is an allowance for what the value of the grain could be earning or saving if it was used elsewhere.

Like the opportunity cost of capital, the rate could be based on an alternative investment or the debt finance rate during the same period grain is stored. For example, if the grain was sold at harvest the funds could be used to pay off debt rather than waiting for the grain payment some months after it has been stored.

The rate used needs to be consistent for the opportunity cost of capital and the opportunity cost of the stored grain as well as the rate used for comparing grain storage with other farm investment options.

S CALCULATION

Grain price at harvest x opportunity cost or interest rate ÷ 12 months to get a monthly rate x number of months grain is stored.

Example:
$350/t x 6% ÷ 12 months x 6 months = $10.50

T Insect treatment

While strict hygiene and aeration cooling can reduce the need for insect pest treatments, it would be optimistic budgeting not to include a treatment cost for grain stored longer than a couple of months.

The treatment cost will vary according to the length of time grain is stored and the product that can be used in each type of storage.

If budgeting on using phosphine (or any other fumigant or controlled atmosphere) then a gas-tight silo is required for reliable fumigation that prevents resistance developing in pest species.

For more information on grain storage insect pest control, see Section 4 Grain storage insect pest identification and management.

T CALCULATION

Treatment cost x number of treatments

Example: $0.40 x 1 treatment = $0.40/t

Photo 3: *Insect control: If the plan is to store grain for longer than a couple of months, an insect control option will be required at some stage. (Source: Chris Warrick, Primary Business)*

U Bags and bunker tarps

The cost of grain bags is a simple calculation as they are a single-use item with a known storage capacity. Bunker tarps may require some estimation to account for tarps that can be used more than once.

U CALCULATION

Price of bag ÷ bag capacity
Example for bags: $1300 ÷ 240 t = $5.42/t

Example for bunker tarps:
$10,500 ÷ 1000 t ÷ 3 uses = $3.50/t

Photo 4: *Consider the cost of hiring or owning the inloading and out-loading machines. (Source: Tim Sait)*

V CALCULATION

Grain price x percentage lost

Example:
$340/t x 0.2% = $0.68/t

V Shrinkage

Shrinkage is an allowance for grain spilt or lost during storage. The amount lost depends entirely on the type of storage infrastructure and care taken by the operator.

For example, bunkers, pits or sheds are likely to have more losses than cone-bottom silos.

W CALCULATION

Contract dryer: total drying cost or hire cost ÷ total tonnes dried = cost $/t

Example for contract dryer: $20,000 ÷ 1000 t = $20/t

Batch dryer: ((annual depreciation and repairs and maintenance + opportunity cost of capital) ÷ annual tonne throughput) + ((fuel cost/hr + labour rate/hr) ÷ throughput t/hr)

Example for batch dryer:
Step one: ((($160,000 x 7%) + ($160,000 x 6%)) ÷ 1500 t/yr) + (($100/hr + $45/hr) ÷ 20 t/hr)

Step two: (($11,200 + $9600) ÷ 1500 t/yr) + ($145/hr ÷ 20 t/hr)

Step three: ($20,800 ÷ 1500 t/yr) + $7.25/t

Step four: $13.87/t + $7.25/t = $21.12/t

Calculation for aeration drying: ((fan motor size x electricity cost x run time) + (labour rate x time to manage drying process)) ÷ storage capacity

Example for aeration drying: ((7.5 kW x $0.30/kWh x 240 hrs) + ($45/hr x 5 hrs)) ÷ 50 t = $5.94/t

W Drying

If one of the aims of on-farm storage is drying for early harvest then a drying cost needs to be accounted for.

There will be several ways to calculate drying cost depending on the drying method, the amount of moisture being removed from the grain and the ambient conditions at the time.

In-storage aeration drying requires airflow rates of at least 15-25 L/s/t, usually delivered by large fans with 7.5 kW, three-phase electric motors. Ambient relative humidity and fan airflow will vary the fan hours required, so the cost of aeration drying will vary, but an example is provided below. For more information on aeration drying, see Section 7 Managing high-moisture grain.

X Total variable costs

Adding up all the variable costs determines the cost of storing each tonne of grain on farm. If the storage already exists, then knowing the variable costs can help with the decision at harvest time whether to store on-farm or deliver straight to the bulk handler.

Any positive difference between the benefits and the variable costs essentially goes towards paying the fixed costs which we spent when the storage was purchased.

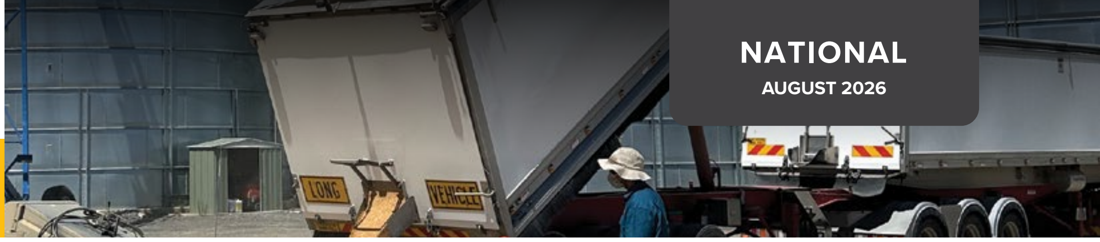
Y Total cost of storage

Adding the fixed costs and variable costs together gives the total cost of the on-farm storage facility. This reveals the return required, from storing grain, to cover all the associated costs of on-farm storage.

Z Profit or loss on storage

The budgeted gain or loss of storing grain on farm can be determined by subtracting the total costs from the total benefits. A positive figure is profit, a negative figure means storing grain on farm is likely to cost money rather than make money.

This profit/loss figure can also be used to compare on-farm storage with the benefits vs costs of marketing options such as warehousing.



CALCULATION

Profit on storage ÷ capital cost of storage x 100

Example:
$30.90/t ÷ $250/t x 100 = 12.4% ROI

CALCULATION

Capital cost ÷ profit on storage

Example:
$250/t ÷ $30.90/t = 9 years

2.2 The analysis

2.2.1 Return on investment

Providing storage is profitable, the margin ($/t) divided by the capital cost of the storage ($/t) multiplied by 100 is the percentage return on investment (ROI).

An ROI is simply the return or income as a percentage of the capital invested so is a practical way to compare like with like.

Use this ROI figure to compare grain storage to other investment options.

2.2.2 Payback period

An alternative to using ROI is to calculate the payback period. That is, assuming the budgeted figures are achieved, how many years will it take for the storage to pay for itself.

2.2.3 The decision — to invest or not to invest

While it's difficult to put an exact dollar value on each of the potential benefits and costs, a calculated estimate will determine if it's worth more thorough investigation.

If the investment of on-farm grain storage is compared with other investments and the result is similar, consider revisiting the numbers and working on increasing their accuracy.

If the return is not even in the ball park, a costly mistake has potentially been avoided.

On the contrary, if the return is favourable, it is worth proceeding with the investment confidently.

Evidently the financial implications are not the only factor to consider in deciding between investment options.

Labour availability, knowledge and area of interest will also play a part in the success or otherwise of the storage.

If the figures do add up to be the best financial investment option, the ultimate test is to consider if on-farm storage is going to get the business closer to achieving its strategic goals.

Grain storage investment checklist

If the calculation doesn't produce the answer you were expecting, try following this checklist:

- ✓ Carry out a reality check on the assumptions/estimates used.
- ✓ Check each of the benefits and costs have been calculated correctly making sure they yield a benefit or cost per tonne.
- ✓ Check the costs and benefits have been totaled then subtracted correctly
- ✓ Check the ROI calculation has been done following the example provided.
- ✓ Ensure you are looking at the investment objectively, putting aside biases (and pride if the investment has already been made).
- ✓ Try varying the cost and/or benefits to see what effect they have on the outcome. A useful one to start with is the length of time in storage, which affects the opportunity cost of grain in storage. Remember to alter the benefits in line with the time held in storage.
- ✓ Do the calculation on a different storage type for a comparison.
- ✓ Contact one of the grain storage specialists for assistance.
  info@storedgrain.com.au
  1800 WEEVIL

MORE INFORMATION

[RIRDC: OH&S Managing Grain Production Safely]

[AgriFutures Australia: WHS for grain farms]

VIDEOS

[GCTV Stored Grain: Stay Safe Around Grain Storage]

Safety around grain storage

The fundamental approach to grain storage safety is the same as for all other farming activities. The aim is to have a safe workplace for everyone on the farm, including workers, contractors, families, visitors and the owner/managers.

Start by identifying any hazards associated with the grain storage site. This involves talking with workers who use the site, taking time to thoroughly inspect the site and equipment and seeking advice and information from industry and workplace health and safety (WHS) organisations to help identify risks that may not be initially apparent.

Secondly, assess the risk of each hazard in terms of its potential severity. If an accident occurred due to the identified hazard, would it result in scratches and bruises or is there potential for someone to be seriously injured or killed?

The third step is to address the hazard, starting with the highest-risk hazards first. The ultimate aim is to totally remove the risk, but where that's not possible, find a way to control it. This could mean altering the way activities are carried out or providing protective equipment.

After controlling the risk as much as possible, it is important to develop a plan of action in the event an accident does occur. For example, if a worker is exposed to phosphine gas, or another harmful chemical, ensure emergency phone numbers are readily available to get medical help.

Training for everyone who works around grain storage is required and may be performed by a mixture of experienced operators and qualified, specialist trainers. Safety topics include: Identifying and managing risks, operating grain handling machinery and storages, grain testing and record keeping, working from heights, working in confined space, chemical handling and fumigation.

3.1 Designing a safe storage facility

Regardless of the type of grain storage used, selecting a suitable site is the first consideration when designing a safe grain storage system.

If the storage site is already established, assess the site for the following safety considerations and potential for improvement.

If considering future expansion, it may be beneficial to build a new site and decommission the current site when it reaches the end of its working life.

SAFETY TIP

Site safety considerations include:

- *Surroundings* — locate the storage site away from overhead powerlines, houses where children might play, or houses or work areas that will be affected by dust and noise from grain storage activities.
- *Access* — ensure safe access for trucks turning into and out of the site from public roads without endangering other road users.
- *Expansion* — ensure the site is clear of trees, sheds and permanent structures to allow for expansion without having to manoeuvre trucks and augers in a cramped area.
- *Drainage* — select a relatively level site for easy and safe manoeuvring of augers and trucks, but ensure sufficient drainage is available to prevent having to work in wet, slippery and boggy conditions.

For more information on silo safety, see Section 1.2 Grain storage considerations.

3.2 Smart storage selection

Choose storage that is cost effective and practical for the volume of grain to be stored. Considering safety in the mix makes for the ultimate storage result.

Sheds and bunkers are cost-efficient options for large quantities of grain, but require a considerable amount of manual labour and dedicated equipment to empty.

Silos are comparatively less labour intensive, although the amount of manual shovelling to completely empty silos is significantly reduced by choosing cone-bottom silos or flat-bottom silos with well-designed sweep augers.

Cone-bottom silos are the obvious choice for easy and safe out-loading. They are particularly beneficial if filled more than once a year — used as a buffer for harvest logistics.

High-moisture grain and grain with a high percentage of screenings does not empty from standard silos very well, which commonly leads to people being tempted to climb into the silo to shovel out the stubborn grain. It is better to only store these types of commodities in silos with steeper cone-bottom silos or sheds where they can be out-loaded with a front-end loader. If planning to store fertiliser in silos, ensure they are designed specifically for fertiliser storage with a steep cone and a corrosion-resistant internal finish. Avoid storing blended fertilisers that are prone to moisture exchange and caking.

Manufacturers are well placed to provide advice on choosing suitable storage types for various commodities.

3.3 Safety features on silos

SAFETY TIP

Before buying a silo, consider the safety features on offer.

In most cases ladders are still required for monitoring grain in the top of the silo. State-based WHS requirements for ladders exist, but as a guide look for ladders with a safety cage and platforms every two metres, handrails on the top of the silo and a system that prevents children climbing the ladder. Consider an elevated walkway to access the top of a line of silos rather than a ladder on each silo.

Features that limit the need to climb the ladder are a valuable addition to silos and include:

- sight glasses or a device to indicate the level of grain inside the silo;
- a system for applying fumigation at ground level, which will distribute the gas to the headspace in the silo;
- lids that can be opened and closed from the ground. (Be aware that few ground-operated lids can be closed and latched tight enough to be gas-tight for fumigation. Most lids still require a climb to the top of the silo to inspect rubber seals and latch the lid before the silo will meet a half-life pressure test, required for effective fumigation. When checking this point with manufacturers, refer to AS2628 — the Australian Standard for gas-tight silos.)

Consider if certified training is required for working at heights.

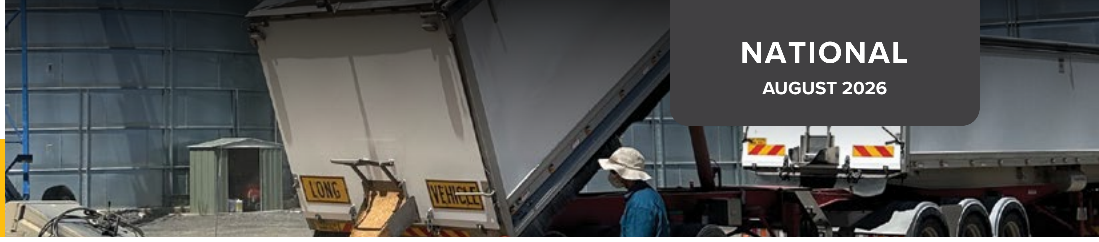


Photo 1: *Safe access to the top of grain storages is essential for monitoring and maintenance (left). Place warning stickers where operators are most likely to see them (right). (Sources: Ben White, Kondinin Group; Chris Warrick, Primary Business)*

VIDEOS

CASA-ACSA: Grain Entrapment

3.4 Safety on the inside

When working in a potentially dangerous environment, such as inside a silo to clean it out after emptying, it is essential to have another person outside to call if help is needed.

Before entering the silo, ensure you are well hydrated and wearing suitable clothing to do the job (for example, sturdy, enclosed footwear).

Avoid heat stress by carrying out the job during a cool time of the day so the internal silo temperature is more comfortable.

SAFETY TIP

Before entering a silo:

- Consider if certified training is required to enter and work in confined spaces.
- Open all lids and ventilation points well before entering to allow as much free-flowing air as possible. Damp grain, especially canola, will produce carbon dioxide and carbon monoxide at toxic levels. Monitors are available to test for these gases.
- Ensure all augers or conveyors filling or emptying the silo are stopped and cannot be started by someone else while you are in the silo.
- Stop and think if there is any way the job can be done from outside the silo.
- If entry is not through an access door at ground level, ensure the ladder has an appropriate safety cage. If not, a certified safety harness must be worn.
- Check for bridged or lodged grain that could collapse and do not enter under these circumstances.

While working inside a silo:

- Have someone outside the silo to assist and get help if required.
- Wear an appropriate dust mask and goggles to prevent fine dust particles entering your lungs and eyes.
- If you become trapped under grain, avoid movement and don't panic as this will worsen the problem — try to remain calm and call for help.

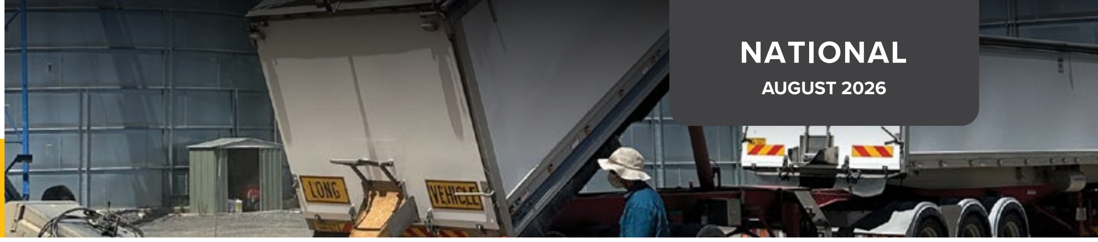
VIDEOS

On-farm grain storage safety

3.5 Filling and emptying

Always fill and empty silos from the middle. Filling or emptying a silo from the sides will cause uneven loading on the silo, potentially causing a structural failure. Ensure augers and conveyors are fitted with adequate guarding.

Wear high-visibility clothing while working around moving machinery to reduce the chance of being run over. Ensure all workers are trained to safely operate the grain storage facilities, filling and emptying equipment and associated machinery.



VIDEOS

GCTV Stored Grain: Fumigation safety

VIDEOS

Masks for phosphine

SAFETY TIP

MORE INFORMATION

Respirators and filters for phosphine fumigations

Fatigue and stress are common during harvest; ensure all operators get enough rest or downtime to avoid fatigue and stress-related accidents.

Photo 2: *Having a large gravelled area around silos enables machinery to be moved into position safely. Always fill silos from the centre to avoid uneven loading. (Source: Chris Warrick, Primary Business)*

3.6 Stored grain fumigants and chemicals

Even though alternative fumigants are becoming more readily available, phosphine is still widely relied upon to control pests in stored grain.

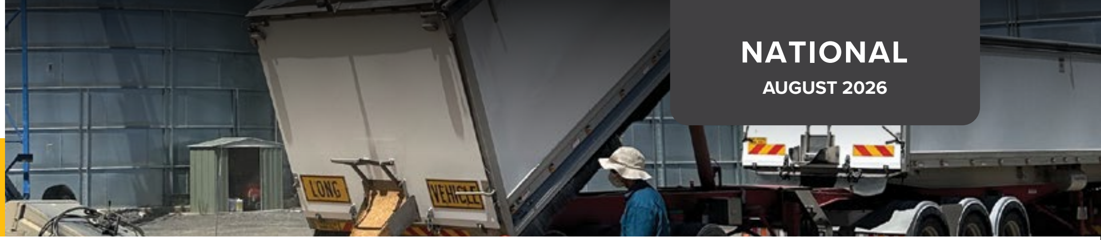
Phosphine is potentially one of the most dangerous products used on farm, which is why it is classed as a schedule seven poison, indicated on the label — DANGEROUS POISON.

As a minimum requirement, the label directs the use of elbow-length PVC gloves and a full-face breathing respirator with a combined dust and gas cartridge.

Never rely on the odour of phosphine to determine if the atmosphere is safe. The odour threshold of phosphine (for those that can smell it) is two parts per million (ppm). Both the Time Weighted Average (TWA) and short term or peak exposure limits are lower than this, which means by the time phosphine can be smelt (2 ppm) the gas concentration level is already exceeding the safe exposure limits.

Always read the product label and Material Safety Data Sheet (MSDS) for safety information and required personal protection equipment (PPE). The respirator must be fitted with a combined dust and gas cartridge (canister) suitable for phosphine, often listed under inorganic gases. Be aware that cartridges have a limited lifespan as they contain activated carbon. Store in a sealed container when not in use and follow manufacturer directions for replacement.

Photo 3: *A full-face breathing respirator is required for handling phosphine. The respirator must be fitted with a combined dust and gas cartridge (canister) suitable for phosphine. (Source: Ben White, Kondinin Group)*



MORE INFORMATION

Grain Storage management equipment (Phosphine meters, sign suppliers and other safety equipment)

Personal phosphine monitors (low range) are simple to use and provide an additional level of protection when working around fumigated grain storages. The monitors clip onto the operator's collar within the breathing zone and alarm when phosphine concentrations exceed the short-term exposure limit (STEL), peak exposure limit or time-weighted average (TWA).

These monitors are particularly useful when working around storages during fumigation or venting. With the addition of a sampling pump, they can also be used to confirm grain has been adequately ventilated before out-loading.

Always follow product label directions and comply with the current Safe Work Australia Workplace Exposure Limits.

Place a warning sign on the silo to tell others to stay away. The sign must contain the words DANGER — POISONOUS GAS, KEEP AWAY.

For more information on fumigation, see Section 6.1 Fumigating with phosphine.

3.7 State Worksafe organisations and government WHS contacts

Safe Work Australia

SAFETY TIP

Safe Work Australia

W www.safeworkaustralia.gov.au

SafeWork NSW

W www.safework.nsw.gov.au
T 13 10 50

SafeWork SA

W www.safework.sa.gov.au
T 1300 365 255

Workplace Health and Safety QLD

W www.worksafe.qld.gov.au
T 1300 362 128

WorkSafe Tasmania

W www.worksafe.tas.gov.au
T 1300 366 322

NT WorkSafe

W worksafe.nt.gov.au
T 1800 019 115

WorkSafe Victoria

W www.worksafe.vic.gov.au
T 1800 136 089

WorkSafe WA

W https://www.worksafe.wa.gov.au/
T 1300 307 877

WorkSafe ACT

W www.worksafe.act.gov.au
T 13 22 81

MORE INFORMATION

QDAF Fact Sheet: Identification of the flat grain beetles (*Cryptolestes* spp.) of Australia

MORE INFORMATION

Insect resistance testing contact details

Grain storage insect pest identification and management

If stored grain is not properly managed, it can become infested with stored-grain pests. Grain intended for domestic human consumption, and particularly grain for export, must be free of live insects.

Regular inspections, including sieving grain samples from both the top and bottom of silos, provide an early warning of insect activity and infestation.

Probe traps installed towards the top of the grain stack can detect insect activity well before insects become visible on the grain surface.

Protecting stored grain from insect attack makes sound economic sense. Even feed grain can lose value through reduced nutritional quality and palatability, affecting livestock performance.

Seed grain is an investment in the following season's crop. If boring insects are present, they can damage or destroy the grain embryo, reducing germination.

For assistance identifying stored-grain insects or testing insect samples for phosphine resistance, use the link opposite to contact your nearest laboratory.

4.1 Key pest species

The most common insect pests of stored cereal grains in Australia are:

- Lesser Grain Borer: (*Rhyzopertha dominica*)
- Rust-Red Flour Beetle: (*Tribolium* spp.)
- Rice Weevil: (Sitophilus spp.)
- Flat Grain Beetle: (*Cryptolestes* spp.)
- Saw-Toothed Grain Beetle (*Oryzaephilus surinamensis*)
- Psocids *(Liposcelis* spp.*)* – Booklice
- Bruchids: Cowpea weevils (*Callosobruchus* spp)
- Pea Weevil (*Bruchus pisorum*)

MOTHS:

- Angoumois Grain Moth (*Sitotroga cerealella*)
- Indian Meal Moth (*Plodia interpunctella*)
- Warehouse Moth (*Ephestia* spp.)

Figure 1 provides a useful guide to identifying the five most common stored-grain pests.

VIDEOS

QDAFF: Diagnosing pest using digital microscopes

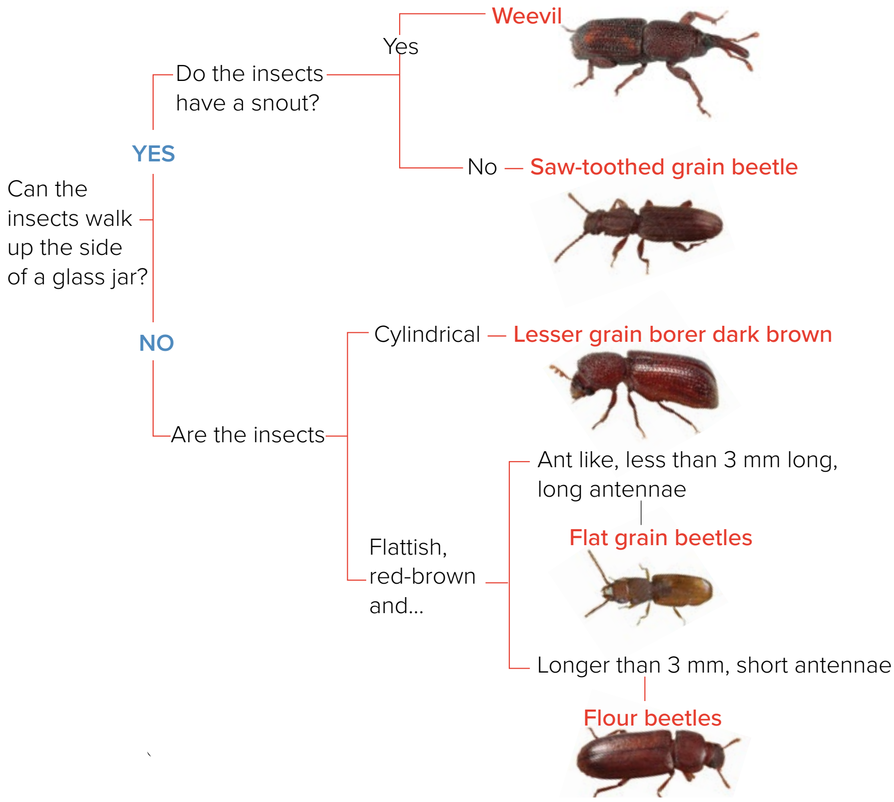


Figure 1: *Identification of common pests of stored grain*
Source: DAF, QLD

4.1.1 Lesser grain borer (*Rhyzopertha dominica*)

Photo 1: *Lesser grain borer (*Rhyzopertha dominica*) (Source: DAF, QLD)*

A serious pest of most stored grains: the Lesser Grain Borer has developed resistance to a number of grain insecticides.

Key Features:

- Dark brown cylindrical shaped beetle (up to 3 mm long) with club-like antennae
- Viewed from the side, the beetle's mouth parts and eyes are tucked underneath the thorax (chest)
- Adult beetles are strong flyers.

Life cycle:

- Life cycle completed in four weeks at 35°C and seven weeks at 22°C. Breeding stops below 18°C
- Females lay between 200-400 eggs on grain surface. Young larvae (white with brown heads) initially feed outside then bore into the grain
- Adults live for 2-3 months.

Detection:

- Their habit is to remain hidden in grain. Regular sampling and sieving is required for detection.

4.1.2 Rust-red flour beetle (*Tribolium castaneum*)

Photo 2: *Rust-red flour beetle (*Tribolium castaneum*) (Source: DAF, QLD)*

Commonly found in stored cereal grain, processed grain products, oilseeds, nuts and dried fruit.

Key Features:

- Adult beetles (3-4.5 mm long) bright reddish-brown in colour when young and a darker brown when older
- Three larger segments on end of antennae
- Similar species: Tribolium confusum – confused flour beetle, more common in cool, temperate regions.

Life cycle:

- Life cycle completed in 4 weeks at 30°C, 11 weeks at 22°C and reproduction stops below 20°C
- Adults live from 200 days to two years and fly in warm conditions
- Up to 1000 eggs per female, loosely scattered throughout the commodity
- Cream-coloured larvae feed externally on damaged grain
- Beetles infest whole grain, but breed more successfully on processed products (i.e. flour).

Detection:

- Beetles move quickly and are strong flyers. When in low numbers use sieving and probe traps to detect
- Preferred habitat is around storage areas with poor hygiene, broken grain, gradings or bulk cottonseed.

4.1.3 Rice weevil (*Sitophilus oryzae*)

Photo 3: *Rice weevil (*Sitophilus oryzae*) (Source: DAF, QLD)*

Major pest of whole cereal grains.

Key Features:

- Adults are dark brownish black (2-4 mm long) with a long weevil 'snout'
- Adults have four small light coloured patches on their rear wing covers
- Rarely flies, but climbs vertical surfaces (e.g. glass jar)
- Similar species: Sitophilus zeamais – maize weevil, and Sitophilus granarius – granary weevil.

Life cycle:

- Adults live 2-3 months
- Larvae generally not seen – they feed and develop inside single grains
- Life cycle completed in four weeks at 30°C, 15 weeks at 18°C, breeding stops below 15°C.

Detection:

- Under warm conditions, or when grain is moved, rice weevils are often observed climbing out of grain up vertical surfaces. Sieving & probe traps recommended to detect low numbers.

4.1.4 Flat grain beetles (*Cryptolestes* spp.)

Photo 4: *Flat grain beetle (*Cryptolestes *spp.) (Source: DAF, QLD)*

Infests most stored grain and feeds on damaged grain. Some populations have high levels of phosphine resistance.

Key Features:

- Smaller than other major stored grain pests (2 mm long), very flat, reddish-brown colour with long thin antennae
- Fast moving, seeking cover under grain or trash
- Adults fly readily and can live for several months
- C. ferrugineus most common in Australia, but there are several closely related Cryptolestes species with similar appearance.

Life cycle:

- Life cycle completed in 4 weeks at 30-35°C with moist conditions, 13 weeks at 20°C, breeding stops at 17.5°C
- Larvae, with characteristic tail and horns, feed and develop externally on damaged grains
- Females lay up to 300 eggs loosely in the grain stack.

Detection:

- Sieving and probe traps usually required for detection
- Some populations of flat grain beetles have developed very high levels of phosphine resistance. Send in insect samples for testing after a fumigation failure.

4.1.5 Saw-toothed grain beetle (*Oryzaephilus surinamensis*)

Photo 5: *Saw-toothed grain beetle (*Oryzaephilus surinamensis*) (Source: DAF, QLD)*

Infests cereal grains, oilseeds, processed products, peanuts and dried fruits.

Key Features:

- Dark brown-black beetle (up to 3 mm long), fast moving
- Thorax (chest) has saw-toothed pattern on each side and three distinct ridge lines on top
- Adults climb vertical surfaces (glass jar) and fly in warm conditions.

Life cycle:

- Prefers damaged or processed grain to establish in significant numbers
- Adults can live for several months, females laying 300-400 eggs loosely throughout the grain. White larvae feed and develop externally
- Life cycle completed in 3 weeks at 30-33°C, 17 weeks at 20°C, reproduction stops below 17.5°C.

Detection:

- Sieving and probe traps are recommended for detection
- Has developed resistance to a number of grain insecticides.

4.1.6 Psocids (*Liposcelis* spp.), booklice

Photo 6: *Psocids (*Liposcelis *spp.), booklice (photos left and right). (Source: DAF, QLD)*

Infests a wide range of grains, commodities and storage facilities.

Key Features:

- Very small, soft-bodied and opaque, pale coloured (up to 1 mm long), often appear as a 'moving layer of dust' on grain or storage structures
- A secondary pest, feeding on damaged grain and moulds
- There are three main species of psocids in Australia, often in mixed populations.

Life cycle:

- Thrive under warm, moist conditions – optimum 25°C and 75% relative humidity. Life cycle 21 days
- Eggs are laid on grain surface, hatching to nymphs that moult through to adult stage.

Detection:

- Warm, humid conditions increase activity. Usually observed in storage or on grain surfaces. Sample and sieve to detect when in low numbers.

4.1.7 Bruchids: Cowpea weevils

Photo 7: *Cowpea weevil (*Callosobruchus *spp) (Source: DAF, QLD)*

Callosobruchus spp are pests of most pulse crops, including mungbeans, cowpeas, field peas, chickpeas, soybeans and lentils.

Key Features:

- Adults (up to 4 mm long), emerge through perfectly round holes in the seed
- Globular, tear-shaped body is reddish brown with black and grey markings
- Wing covers (elytra) do not fully cover the abdomen
- Adults have long antennae, climb vertical surfaces (glass jar) and are strong flyers.

Life cycle:

- Adults do not feed, but lay 100 white eggs clearly visible on the outside of seed. Adults have a short lifespan of 10-12 days. Unlike most storage pests, adults may also lay eggs on mature seed pods in a standing crop
- Larvae feed and develop within individual seeds and emerge as adults leaving a neat round hole.

Detection:

- A common problem in warmer months for mungbeans.
- Fortnightly thorough sampling and sieving is important to prevent serious losses.

4.1.8 Pea Weevil (*Bruchus pisorum*)

Photo 8: *Pea weevil (*Bruchus pisorum*) (Source: SARDI ENTOMOLOGY)*

Both a field pest and storage pest (appears in storage after emergence). In WA it is a major pest of field peas.

Key Features:

- Adult globular body length (4-5 mm long) with long legs and antennae
- Wings (elytra) are patterned with white/cream spots
- Do not breed in stored dry peas, adults lay and glue eggs onto pods in standing pea crops before harvest
- Adult emerges through a neat round hole in the seed
- Adults are strong flyers, they reappear in spring to visit flowers to feed on the nectar then seek out new field pea crops to lay eggs.

Life cycle:

- Hatching larvae bore through the seed pod and into a single seed where they feed, grow and pupate
- Breed one generation per year. Adults are long-lived, overwinter and do not feed on field peas.

Detection:

- Adults migrate into crops from seed sources and nearby trees where they shelter under the bark
- Field peas should be regularly checked, in and around the crop edges when first pods are forming using a sweep net when temperatures are above 18°C
- Check pea seed for neat round holes (evidence that adults have emerged).

MOTHS:

Angoumois Grain Moth (*Sitotroga cerealella*)

Photo 9: *Angoumois Grain Moth (*Sitotroga cerealella*) (Source: CSIRO)*

A pest of whole cereal grains which infests only the surface layers of bulk-stored grains. Infestation of standing maize crops before harvest is quite common, occasionally in other cereal crops.

Key Features:

- Silvery grey to grey brown wings which taper to a point
- Wings have a long fringe of fine hairs along the posterior edge
- Adults (5-7 mm long) are unable to penetrate grain, therefore only infest surface layers of bulk grain.

Life cycle:

- Adult moths do not feed but lay 150-300 eggs on or near the grain surface. This pest does not create webbing
- Larvae burrow into a single grain and feed and develop until the adult moth emerges in 10-14 days through a visible hole
- Life cycle takes around 5-7 weeks in warm conditions.

Detection:

- Take regular monthly samples and look for moths near grain surface. When adults emerge, pupal cases are often found protruding from grain.

Indian Meal Moth (Plodia interpunctella)

Photo 10: *Indian Meal Moth larvae (*Plodia interpunctella*) (Source: CSIRO)*

A pest in flour mills, processing plants, dried fruit and on the surface of all types of grains.

Key Features:

- Adults (5-7 mm long), distinctive bicoloured wings – dark reddish brown on rear half of the wing and grey at the front.

Life cycle:

- Female moths lay 200-400 eggs on the foodstuff
- Larvae create webbing as they feed. They then pupate in several grains webbed together in a clump
- In summer life cycle takes about 4 weeks.

Detection:

- Take regular monthly samples and look for webbing and moths near grain surface
- Also check in residues on grain harvesting and handling equipment.

Warehouse Moths (*Ephestia* spp)

Photo 11: *Warehouse moth larva (*Ephestia *spp) (Source: CSIRO)*

A pest of flour mills, food processing plants, cereal grains and oilseeds.

Key Features:

- Adult moth body length is 8-10 mm
- Moth has grey wings with many fine, dark wavy markings, including lighter stripes extending horizontally across each forewing
- Extensive webbing created by larvae is visible on the grain surface.

Life cycle:

- Adult moths do not feed and are short-lived. Female lays between 100-270 eggs over a two-week period on or near grain
- Caterpillar is coloured light pink with a small black spot at the base of each hair
- Full life cycle 30 days under ideal conditions, 30°C and 75% relative humidity.

Detection:

- Take regular monthly samples and look for webbing and moths near grain surface. All moths are typically active at dusk and dawn.

Phosphine-Resistant Insects

- Saw-Toothed Grain Beetle and Lesser Grain Borer have developed some resistance to a number of grain insecticides.
- Flat Grain Beetle: some populations (confusingly sometimes called Rusty Grain Beetle or *Cryptolestes ferrugineus*) have developed high levels of phosphine resistance.
- A range of stored grain insects are becoming harder to kill with phosphine fumigations.
- Threatens exports, as phosphine may become ineffective against some pests.
- Poor fumigation practices increase resistance (e.g. repeated fumigations in unsealed or poorly sealed storages).
- Strong phosphine resistance is also found in overseas countries.
- Live insects detected following fumigation should be tested for resistance.
- Resistant insects can fly between stores or be transported in machinery.

Exotic pests: Not present in Australia – be on the lookout

The following pests have serious potential impact on the value of grain if detected in Australia. If you see anything unusual, report it to your local state department of primary industries or phone the Exotic Plant Pest Hotline, 1800 084 881

Karnal bunt (*Tilletia indica*)

Photo 12: *Karnal bunt (*Tilletia indica*) (Source: PaDIL)*

- Can infect wheat, durum and triticale.
- Usually only part of each grain is affected. Infected stored grain will have a sooty appearance and will crush easily, leaving a black powder.
- Infected grain often has a rotten fish smell, flour quality is seriously reduced.
- Symptoms are similar to common bunt.

Khapra beetle (*Trogoderma granarium*)

Photo 13: *Khapra beetle (*Trogoderma granarium*). (Source: Ministry of Ag. and Regional Development)*

- Attacks most stored grains.
- Larvae are covered in fine hairs.
- Looks identical to the warehouse beetle to the naked eye.
- Causes grain loss in storage.
- Larvae skins contaminate grain and cause allergies on consumption.
- Phosphine fumigation is not reliably effective.

4.2 Monitoring for insect pests

Regular monitoring means problems are detected early and can be managed before significant grain damage occurs. It also avoids surprises at out-loading, prevents costly rejections from grain buyers and maintains your reputation for supplying quality grain.

To maintain grain quality and to select the correct treatments, identify pests early by sampling monthly. In warm conditions (>30°C) many grain pests can complete their life cycle in as little as 3-4 weeks causing significant damage.

Grain kept for seed or stockfeed is a common breeding ground for pests so monitor all grain storages every two weeks during warmer periods of the year.

Use grain insect sieves and probe traps to monitor for pests in all stored grain and regularly check grain handling equipment during the off season.

Finding grain pests early allows them to be identified, treated appropriately and removed before they spread and become a much larger problem, which may be more difficult to treat.

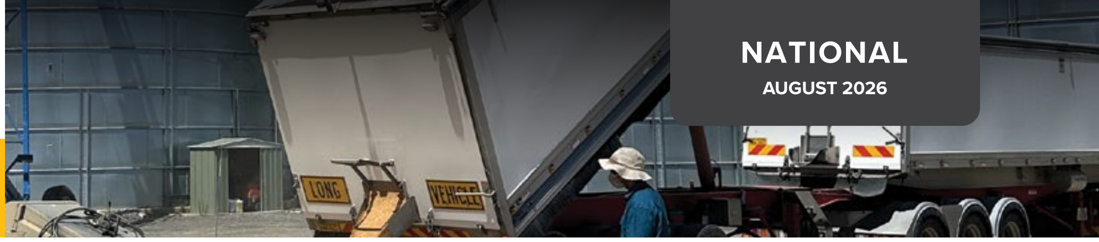
It's useful to understand that for every live adult insect found, there can typically be a ratio of 90 or more insects in immature life stages (egg, larvae and pupae), which will infest the grain when conditions enable them to develop.

For more information on grain storage insect pest control, see
Section 5 Preventing stored-grain pest infestations.

4.2.1 Sampling stored grain

Collect samples from the areas where insects are most likely to establish first. These areas are generally around openings — hatches, doors, aeration fan inlets, filling and emptying points.

The most common place for insects in a silo is at the top, just below the surface of the peak of grain (see Figure 2). This is because it is the last part of the grain bulk reached by aeration cooling or drying. It is also exposed to heating from the headspace and is more susceptible to condensation.



SAFETY TIP

Always follow workplace health and safety guidelines and only climb to the top of a storage if it's safe to do so.

For more information on staying safe around grain storage facilities, see [Section 3 Safety around grain storage.]

Always collect samples from beneath the grain surface. At the bottom of a silo this means opening an outlet to run a small amount of grain out. A sampling probe is ideal for collecting grain from the top of a silo, but it's often impractical or unsafe to climb up a silo with a sampling probe.

VIDEOS

Using Probe Traps

Photo 14: *Probe traps left in the top of a storage can be removed and checked at each inspection. Tie the trap to something inside the storage so it doesn't get lost if it's forgotten about before out-loading. Position the trap so a small amount is left out at the top of the grain to capture insects crawling across the surface as well as those hiding beneath. (Source: Chris Warrick, Primary Business)*

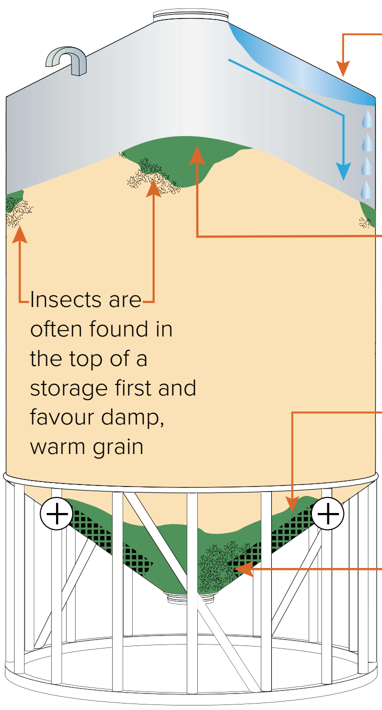


Figure 2: *Common problem areas in grain stores*

Source: Kondinin Group

VIDEOS

Sieving For Grain Pests

4.2.2 Checking for insects

Grain pests can be difficult to detect because they are small, fast moving and some remain hidden in the grain while others can be seen on the surface. There are numerous ways to detect them.

Secure a probe trap to the inside structure of the storage so it doesn't get lost or forgotten about before out-loading. Position the trap in the grain so a small amount is protruding out the top of the grain to capture insects crawling across the surface as well as those hiding beneath.

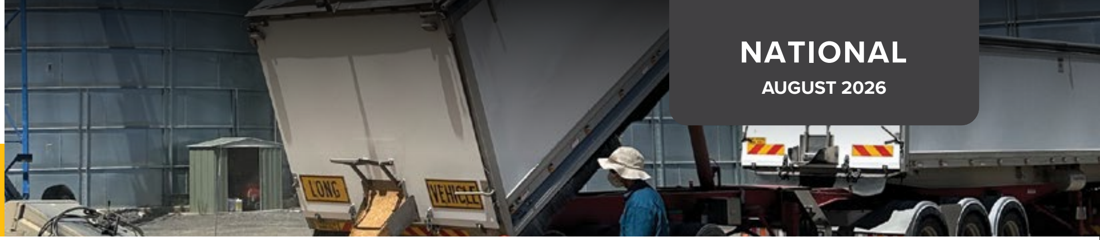
When a sample has been taken, sieving is one of the most effective methods of detecting grain pests. Sieve samples from the top and bottom of stores to detect low levels of insects early. Sieving samples onto a white tray will make it easier to see small insects.

Holding the tray in the sunlight warms the insects and encourages movement making it easier to identify them and quantify population numbers.

A clean glass container helps to identify grain pests. Place the live insects into a warm glass container (above 20°C so they are active, but not hot or they will die).

Weevils and saw-toothed grain beetles can walk up the walls of the glass easily, whereas flour beetles and lesser grain borers are generally unable to climb smooth glass. Look closely at the insects walking up the glass — weevils have a curved snout at the front but saw-toothed grain beetles do not.

Photo 15: *Sieve a one litre sample onto a white tray. Hold the tray in sunlight to warm for 20-30 seconds to encourage insect movement for easier identification. Some insects will continually seek refuge under grain while others stay out in the light — take time to look closely with a magnifying glass. (Source: Ben White, Kondinin Group)*



VIDEOS

Monitoring Grain Temperature

VIDEOS

Monitoring Grain in Storage

MORE INFORMATION

Seeds need cool, dry conditions, no matter the variety

4.2.3 Temperature and moisture

Freshly-harvested grain usually has a temperature around 30°C, which is an ideal breeding temperature for storage pests (see Table 1).

Studies have shown that rust-red flour beetles stop breeding at 20°C, lesser grain borer at 18°C and below 15°C all storage pests stop breeding.

Monitoring grain temperature is not only required to manage aeration, it can indicate potential insect activity in the grain stack. Insect activity generates heat, which provides favourable conditions for mould, impacting on grain quality.

When checking grain temperature, go beneath the surface, measuring in the same spot each time. Record test results to identify any temperature spikes, which will prompt further investigation.

Monitoring grain temperature can be done by:

- Inserting a portable temperature probe into the grain and waiting for the reading to stabilise.
- Leaving a digital thermometer with a one-metre cable in the grain, which can be viewed monthly. Tie it to the silo roof in case it's forgotten when out-loading.
- Installing a remote monitoring cable or spear into the storage which sends temperature and moisture data to a smart phone or web portal.

Check any electronic devices used for monitoring can withstand fumigation with phosphine or remove them prior, to avoid damaging electronic components.

Grain moisture content influences insect activity and mould (see Table 1). Identifying a change in moisture can reveal an issue before it causes significant damage. For example, an increase in grain moisture at the top of a storage could be a result of a leak, condensation or problem with aeration management.

Seed moisture content and storage temperature have a profound influence on grain viability. Aeration cooling is essential for reducing grain temperature after harvest, helping to preserve seed quality and minimise the risk of insect infestation.

GRDC-supported research by Agriculture Victoria found that, regardless of the season, higher grain moisture contents and storage temperatures accelerated the decline in seed germination and viability. Seed variety had little influence on this response. Under high-temperature (30-35°C) and high-moisture (14%) storage conditions, mean germination declined to around 23% over 48 weeks.

Regardless of storage conditions, grain intended for sowing should always be tested for germination and vigour before planting.

Table 1: The effect of grain temperature and moisture on stored grain insect and mould development

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

VIDEOS

Grain storage hygiene

Preventing stored-grain pest infestations

When it comes to controlling stored-grain pests, prevention is better than cure. Grain residues in storages and carry-over grain from previous seasons provide ideal breeding sites for insect pests. Meticulous grain hygiene, combined with structural treatments such as diatomaceous earth (DE), is one of the most effective ways to reduce pest populations before grain enters storage.

5.1 Hygiene before harvest

The first grain harvested each season is often at the greatest risk of insect infestation because even small amounts of residual grain can harbour large pest populations. In one on-farm study, more than 1,000 lesser grain borers were recovered from the first 40 L of wheat passing through a harvester that had been considered clean at the end of the previous season.

Before harvest, remove all grain residues from empty storages and grain-handling equipment, including harvesters, field bins, augers and silos, to minimise the risk of contaminating new-season grain.

Clean equipment by blowing or washing out grain residues and dust, then consider applying an appropriate structural treatment after the annual maintenance is complete.

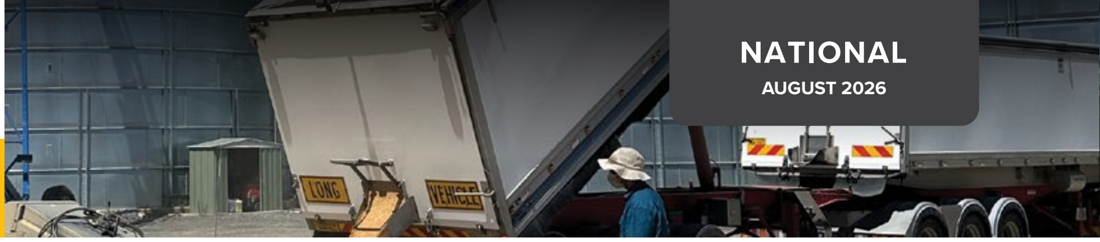
Remove and dispose of any grain remaining in hoppers, bags and other equipment around the storage site, as these residues provide an ideal breeding habitat for stored-grain pests during the off-season.

Photo 1: *Clean out harvesters and grain handling equipment thoroughly with pressurised air. (Source: Chris Warrick, Primary Business)*

5.1.1 Keeping it clean

A single bag of infested grain can produce more than one million insects in a year. These insects can walk or fly to nearby storages, establishing new infestations.

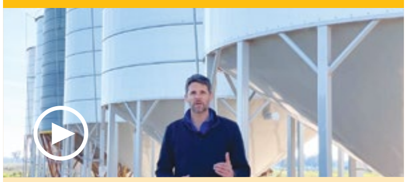
Effective grain storage hygiene involves removing all grain residues that can harbour and support the breeding of stored-grain pests. It also includes regularly inspecting seed and stockfeed grain so infestations can be detected and controlled before they spread.



VIDEOS

Grain storage hygiene – stock feeders

VIDEOS



Winter is the time for grain storage hygiene

5.1.2 Where to clean

Grain hygiene is based on eliminating places where stored-grain pests can survive and breed. This includes all grain storages and grain-handling equipment. Grain pests favour dark, sheltered locations and breed most rapidly under warm conditions.

Common places where pests are found include:

- empty silos and grain storages
- aeration ducts
- augers and conveyors
- harvesters
- field bins and chaser bins
- left-over bags or drums of grain
- trucks
- spilled grain around grain storages piled more than 20 mm deep
- equipment and rubbish around storages
- seed grain
- stockfeed grain and feeding equipment.

Successful grain hygiene involves cleaning all areas where grain gets trapped in storages and equipment. Even small quantities of residual grain can harbour insect pests, allowing fresh grain entering the storage or equipment to become infested.

5.1.3 When to clean

Immediately after harvest is the best time to clean grain-handling equipment and storages, before insect pests have an opportunity to establish. Discarding the first few bags of grain at the start of the following harvest is also good practice, as they are more likely to contain insects or grain residues remaining in the machinery.

Research in Queensland found that stored-grain insects are least active during the colder months of the year, making this an ideal time to carry out thorough cleaning and structural treatments.

Cleaning around silos in July-August can reduce insect numbers before they become mobile and start breeding more rapidly.

Photo 2: *A concrete slab under silos makes cleaning easier. (Source: Chris Warrick, Primary Business)*

Photo 3: *An extended broom handle makes sweeping out silos easier. (Source: Chris Warrick, Primary Business)*

VIDEOS

Dust masks and eye protection

5.1.4 How to clean

The more thorough the cleaning job, the less chance of pests harbouring. The best ways to get rid of all grain residues use a combination of:

- sweeping
- vacuuming
- compressed air
- blow/vacuum guns
- pressure washers
- fire-fighting hoses.

Using a broom or compressed air gets rid of most grain residues, a follow-up wash-down removes grain and dust trapped in crevices and hard-to-reach spots.

Choose a warm, dry day to wash storages and equipment so it dries out quickly to reduce the risk of corrosion.

SAFETY TIP

Remember PPE for lungs, eyes and ears and follow safety procedures if cleaning requires access inside or atop silos.

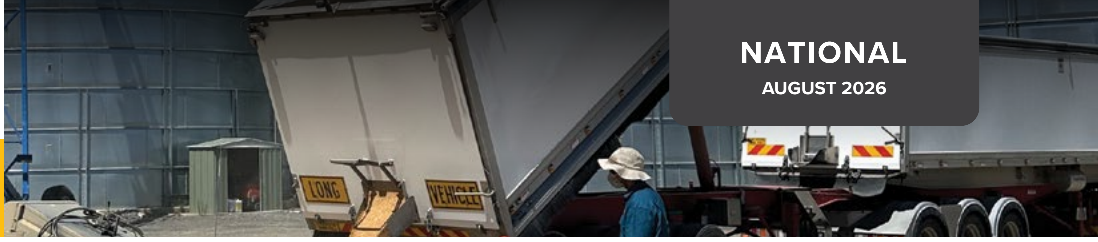
When inspecting empty storages, look for ways to make the structures easier to keep clean. Seal or fill any cracks and crevices to prevent grain lodging and insects harbouring.

Bags of left-over grain lying around storages and in sheds provide an ideal breeding ground for storage pests. After collecting spilt grain and residues, bury, feed to livestock or spread out over the ground at a depth of less than 20 mm and away from the storage so it rots or germinates. Avoid dumping grain within 1 km of storage facilities, as this provides a breeding source from which insects can readily reinfest stored grain.

5.2 Structural treatments

After cleaning grain storages and grain-handling equipment, apply an appropriate structural treatment.

Structural treatments must be used in accordance with label directions. When storing or handling grains such as oilseeds or pulses after application, clean-out prior to use may be required.



MORE INFORMATION

Diatomaceous Earth (DE) Application

VIDEOS

Use DE not lime

VIDEOS

Diatomaceous Earth (DE) application in sheds and silos

Diatomaceous earth (DE) (amorphous silica), including commercial products such as Dryacide, can be applied as either a dust or a slurry to storages and grain-handling equipment for residual insect control (Table 1). DE damages the insect's waxy cuticle, causing it to lose moisture and die from desiccation. When applied correctly to clean, dry surfaces with complete coverage, DE can provide up to 12 months of residual protection against most stored-grain insect pests without the risk of resistance developing. Research indicates there may be some variation in efficacy between DE brands.

Warm, humid conditions reduce the effectiveness of DE so longevity will be less in tropical regions.

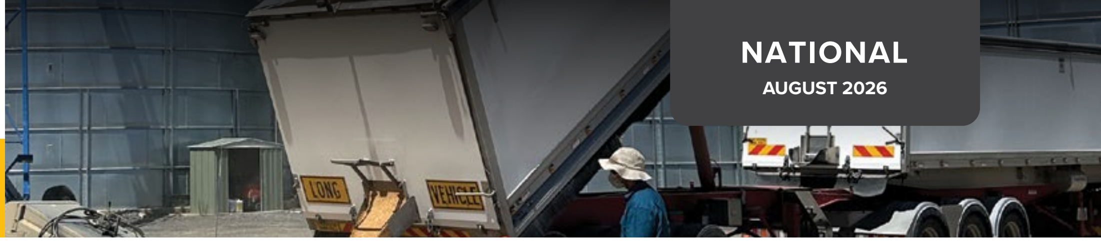
Store DE in a sealed container to prevent it absorbing moisture from the air, which reduces its effectiveness.

Photo 4: *Apply diatomaceous earth aiming for an even coat on the roof, walls and base. (Source: Chris Warrick, Primary Business)*

5.2.1 Applying diatomaceous earth dust

Diatomaceous earth (DE) should be applied using a moving air stream to ensure an even coating of all surfaces. Battery-powered and petrol leaf blowers have proven to be highly effective for applying DE in silos and sheds. As larger flat-bottom silos become more common on Australian farms, higher-capacity petrol blowers provide the most effective distribution in these larger storages.

The venturi attachment shown below can be fitted to a leaf blower to meter DE into the air stream, extending application time and improving the uniformity of coverage.



VIDEOS

Home made venturi for DE application with leaf blower

Photo 5: *Apply diatomaceous earth aiming for an even coat on the roof, walls and base. (Source: Chris Warrick, Primary Business)*

SAFETY TIP

Apply DE to achieve a light, even coating over all internal surfaces, including the roof, walls and floor. The recommended application rate is 2 g/m^2 of treated surface area (Table 1). Uniform coverage is critical to achieving effective residual control. Once application is complete, remove any excess dust by vacuuming or rinsing before filling the storage with grain. Table 1 provides a guide to application rates only. Additional DE may be required where surface area is increased by aeration ducting, false floors or corrugated wall profiles, which can increase the effective surface area by approximately 10%. Although DE is chemically inert, the fine dust can irritate the eyes and respiratory system. Wear a P3 particulate respirator, safety goggles and other appropriate personal protective equipment during handling and application.

Table 1: Diatomaceous earth (DE) application guide

Storage capacity (t)	DE quantity (kg)
80	0.22
100	0.27
120	0.29
150	0.33
300	0.52
1000	1.24
2000	1.94
3000	2.57

Source: Kondinin Group

5.2.2 Silo and shed application

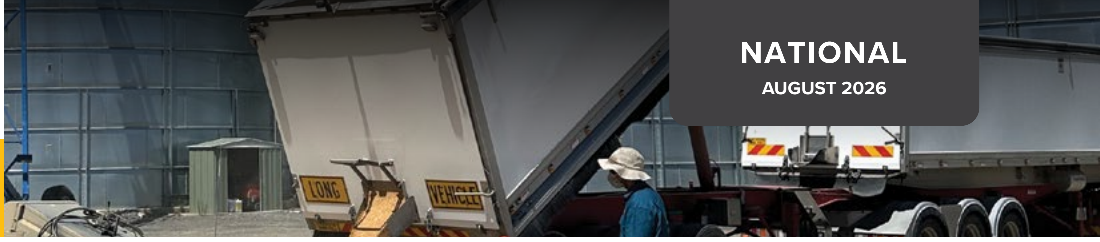
SAFETY TIP

In silos, open all inlets and outlets before applying diatomaceous earth (DE) through the ground access door using a leaf blower and home-made venturi. Applying DE from ground level is safer than applying it through the roof inlet or from inside the silo.

Regularly vary the direction of the air stream to ensure DE is distributed evenly across the roof, walls and floor of the silo. Applying DE over a longer period helps keep dust suspended in the air, improving circulation and promoting more uniform coverage of internal surfaces.

Once application is complete, close all openings to allow the remaining airborne dust to settle throughout the silo. After the dust has settled, reopen at least one opening—such as an aeration fan inlet cover. Empty gas-tight silos should not be left fully sealed, as pressure fluctuations caused by changing ambient conditions can damage the silo. Leaving an opening allows rapid pressure equalisation while still preventing moisture accumulation.

If the silo is fitted with an aeration system, direct DE into the ducting while avoiding the aeration fan motor, where dust may cause premature wear or damage.



MORE INFORMATION

[Diatomaceous Earth (DE) Application in sheds]

Full-floor aeration systems in flat-bottom silos present additional hygiene challenges because dust and grain residues can accumulate beneath the floor. Thoroughly remove residues before applying DE, then finish by sweeping or blowing a light coating of DE beneath the false floor.

Applying diatomaceous earth (DE) as a dust in sheds is effective, although less product is likely to reach higher sections of the roof—particularly above 7.5 m—than will settle on the walls and floor.

Measure the required quantity of DE using the recommended application rate of 2 g/m^2 of treated surface area. Divide the product evenly between several small buckets and position them at regular intervals throughout the shed to promote uniform application.

SAFETY TIP

Fit a P3 particulate respirator and safety goggles. Starting in one corner of the shed, direct the blower towards the upper walls and roof while walking through the shed at approximately 3 m intervals. Apply the DE in a slow, even pattern.

Manual application will inevitably result in some variation in coverage. Aim to achieve a light, even coating across all internal surfaces, paying particular attention to the upper walls and roof, where uniform coverage is more difficult to achieve.

5.2.3 Machinery application

DE can be applied to most equipment used to handle or store grain. For best results, apply it after the equipment has been thoroughly cleaned and all annual servicing and maintenance have been completed. This avoids exposing operators and mechanics to unnecessary dust during maintenance.

Unlike silos and sheds, calculating the internal surface area of grain-handling equipment is generally impractical. Instead, apply DE using a leaf blower and venturi to produce a steady stream of dust through all accessible openings, coating internal surfaces as evenly as possible. Continue until dust is seen emerging from the discharge or outlet points, indicating the equipment has been thoroughly coated.

As a guide, approximately 2.5 kg of DE is required to treat an average harvester.

5.2.4 Applying diatomaceous earth slurry

With the appropriate equipment, DE can also be applied as a slurry, making it well suited to sheds. Although more involved than dust application, the slurry method can provide excellent coverage of internal surfaces. The slurry is mixed in a mixing tank and applied through a flat-fan nozzle with a minimum output of 5 L/min.

Always follow label directions – as a guide, mix DE with water at a concentration of 11 per cent (120 g/L) and apply at a rate of 5 L/100 m^2, equivalent to 6 g/m^2 of dry DE. Apply enough slurry to achieve complete coverage of all surfaces while avoiding runoff.

Impeller pumps are the most suitable for slurry application. A fire-fighting pump with a 3.7 kW (5 hp) engine is typically adequate. Avoid positive-displacement pumps, such as gear or piston pumps, as the slurry can cause blockages. An inline filter with 1000 µm (1 mm) mesh, together with a recirculation line, will help prevent nozzle blockages and keep the slurry well mixed during application.

Where slurry is applied regularly, use a dedicated or older pump, as pumping abrasive slurry will shorten pump life.

Apply the slurry in the same sequence as dust applications, starting at the roof of the silo or shed and working progressively down the walls. Apply a light, even coating while avoiding excessive application that may result in runoff.

A rigid extension lance fitted to the spray hose makes it easier to achieve uniform coverage of high or difficult-to-reach areas, including silo walls and shed roofs.

5.2.5 External structural treatments

Controlling grain storage pests outside of storages is primarily achieved with hygiene as insects cannot survive long without shelter and food. If treatment is required after cleaning outside of storages, DE is unlikely to be effective unless relative humidity remains low for several days and nights.

At the time of printing, chemicals registered for structural treatment of grain storages include Diplomat 500 EC (Chlorpyrifos-methyl 500 g/L), Fyfanon 440 EW (Malathion 440 g/L) and Cislin 25 (Deltamethrin 25 g/L).

While it is registered, resistance to Malathion is high so efficacy is likely to be limited. A mixture of Deltamethrin with Chlorpyrifos-methyl would give the best chance of broad-spectrum structural treatment.

Post-harvest checklist

- ✓ Sweep or blow out all empty grain storages and equipment.
- ✓ Wash down with water on a warm, dry day (if silos can be drained).
- ✓ Apply structural treatment as appropriate.
- ✓ Monitor all stored grain fortnightly during summer, monthly during winter.

5.3 Grain protectants

Grain protectants, combined with meticulous hygiene and aeration cooling, provide effective protection against insect infestations in unsealable storages where fumigation is not possible. (*Protectant options are limited in Western Australia. Always check product registration before purchase and application.*)

Always check with potential grain buyers before applying grain protectants, as some markets do not permit chemical residues.

Grain protectants are designed to prevent insect infestations, not control existing ones. Apply them only to clean, pest-free grain.

The effectiveness of grain protectants is greatly improved when used as part of an integrated pest management (IPM) program. Good hygiene before and after harvest removes breeding sites where pests can survive between seasons, while aeration cooling creates conditions that are less favourable for insect development.

VIDEOS

Grain storage protectant choice

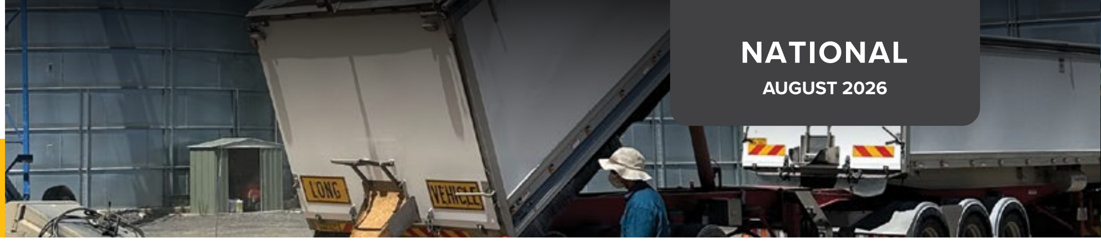
5.3.1 Protectant choice

Always read the product label before selecting a grain protectant to ensure it is registered for use on the grain to be treated and provides effective control of the key stored-grain pests likely to be present. As a general guide, at the time of writing, most grain protectants are registered for use on cereal grains only.

The two main active ingredients used in grain protectants are spinosad (formulated with S-methoprene) and deltamethrin. Rotate active ingredients every one to two seasons, where practical, to help reduce the risk of insecticide resistance developing. Both chemistries provide effective protection against saw-toothed grain beetle, rust-red flour beetle and flat grain beetles. For lesser grain borer, spinosad generally provides superior protection.

Where protection against rice weevil is required, fenitrothion or chlorpyrifos-methyl will need to be included in the mix, depending on the grain type, withholding period and market requirements.

For malt barley, rice and maize, fenitrothion is the only registered mixing partner. However, a 90-day withholding period applies when using the higher application rate for nine months' protection. For other cereal grains, chlorpyrifos-methyl has the advantage of no withholding period, but it is not accepted by some export markets and is therefore more commonly used where grain is destined for domestic markets or on-farm feed.



Some manufacturers offer pre-mixed formulations or packs combining spinosad or deltamethrin with either fenitrothion or chlorpyrifos-methyl, simplifying product selection and application.

Always confirm that the intended grain buyer accepts the chosen protectant, follow all product label directions, and ensure that each chemical active is not applied more than once to any parcel of grain. (*Protectant choice and application options are more limited in Western Australia. Always check current product registrations before use.*)

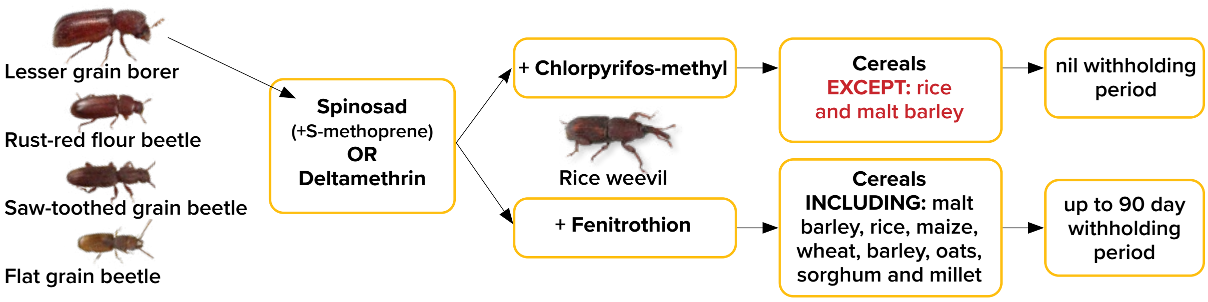


Figure 1: *Protectant choice guide (Not applicable to Western Australia)*

5.3.2 Protectant application guide

For the most even protectant coverage, apply the product to grain as it is augered into storage. The best results are achieved using one, or preferably two, flat-fan nozzles mounted to spray into the auger. Applying protectants at 1 L/t requires thorough mixing as the treated grain travels up the auger to ensure uniform coverage.

Belt conveyors generally do not provide sufficient mixing to achieve even protectant coverage. In addition, liquid application may cause the belt to slip on the drive rollers. Some conveyor manufacturers offer dedicated protectant application systems. Ensure these provide even application to the grain stream and include a means of mixing the treated grain.

Some protectants begin to degrade within 48 hours of being mixed with water, so prepare only the quantity required for immediate use. Always refer to the product label for the anticipated protection period, which is typically three to nine months and may vary according to registered application rates.

Protectants have a shorter effective life when applied to grain above 12% moisture content (MC), grain temperatures above 27°C, or grain exposed to direct sunlight, such as in the ends of sheds or open bunkers.

Check nozzle output and application rate regularly during operation to ensure the correct protectant rate is maintained.

Key components for protectant application systems

- Pump delivery to match auger capacity at 1 L/t plus 10% recirculation
- Bypass line for recirculation and shutoff relief
- Flow regulator or variable position tap
- Flow meter
- Pressure gauge
- Filter
- Flat fan nozzle(s) that are easily removable for checking and cleaning
- Non-return valve to stop siphoning or dribbling once lines are primed

VIDEOS

Stored Grain Protectant Application System Components

5.3.3 Maximum residue limits (MRLs)

As grain markets have become less tolerant of protectants and maximum residue limits (MRLs) are carefully monitored, accurate application is essential.

Some grain protectants have MRLs that are close to the recommended application rate, leaving little margin for error. Accurate calibration and uniform application are therefore critical to ensure residues remain within market requirements. Commodity vendor declarations are also used in many cases to ensure a parcel of grain is only subjected to one application of the protectant to avoid exceeding the MRL. Brief training or stewardship programs are often required prior to purchasing protectants, to ensure proper use is understood and grain marketing is not compromised by misuse.

5.4 Aeration cooling

Aeration of stored grain has four main purposes—preventing mould, inhibiting insect development, maintaining grain quality and managing grain moisture. An additional benefit is that aeration fans can significantly reduce fumigant venting times following treatment (see Section 6.1.7). Grain aeration allows growers to maintain grain quality during storage and while aeration cooling may not eliminate the need for chemical insect control, it will dramatically slow insect development.

While adult insects can still survive at low temperatures, most young storage pests stop developing at temperatures below 18-20°C (see Table 3).

At grain temperatures below 15°C, reproduction of the five most common stored-grain insect pests is effectively halted.

At low temperatures insect pest life cycles (egg, larvae, pupae and adult) are lengthened from the typical four weeks at warm temperatures (30-35°C) to 12-17 weeks at cooler temperatures (20-23°C).

Without aeration cooling, grain is an effective insulator and will maintain its warm harvest temperature for a long time.

Like housing insulation, grain holds many tiny pockets of air within a stack — 100 tonnes of barley requires a silo with a volume of about 130 cubic metres, 80 m^3 is taken up by grain and the remaining 50 m^3 (38 per cent) is air space around each grain.

Without circulation, the air surrounding the grain will reach a moisture (relative humidity) and temperature equilibrium within a few days. These conditions provide an ideal environment for insects and mould to thrive and without aeration the grain is likely to maintain that temperature and moisture for months.

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

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

Source: Kondinin Group

VIDEOS

GRDC: Aeration controllers with Philip Burrill

5.4.1 Air movement within the grain stack

Grain at the top of the stack is the hottest, as heat rises through the grain. The sun heats the silo roof and internal headspace, resulting in the surface grain at the top of the silo heating up (see Figure 2).

When grain is stored at moisture contents above 12 per cent, the air in the headspace heats and cools each day creating ideal conditions for condensation to form, wetting the grain at the top of the stack.

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 2-4 litres per second per tonne, whereas aeration drying requires fans delivering 15-25 L/s/t.

Low-capacity fans cannot carry enough moisture through the grain stack so can't push the drying front through the grain fast enough to dry grain in the top section of a stack before it turns mouldy.

In addition to being inefficient, using high-capacity fans for cooling can potentially introduce moisture causing mould around the aeration duct if run when ambient conditions are above 85 per cent 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.

For more information on aeration drying, to manage high-moisture grain, see Section 7 Managing high moisture grain.

Cooling or drying — making a choice

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 (typically 12.5-13 per cent for wheat or 13.5 per cent for sorghum) can be cooled, without drying, to slow insect development and maintain quality during storage.
- Grain of moderate moisture (up to 15 per cent for wheat and sorghum) 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 and conditions are available.
- High-moisture grain (for example, 16 per cent and higher for wheat and sorghum) will require immediate moisture reduction before cooling for maintenance.
- After drying grain to the required moisture content, cool the grain to maintain quality.

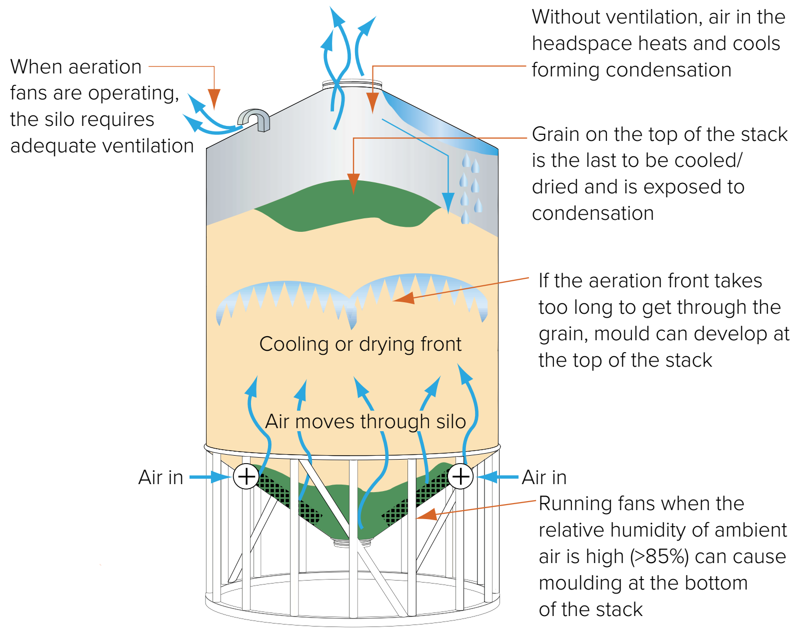


Figure 2: *Air movement within an aerated silo*

Source: Kondinin Group

5.4.2 Uniformity

Without aeration cooling, grain put into storage at warm harvest temperatures will hold these temperatures for a long time, see Figure 3. With 38 per cent of the storage area still taken up by air between individual grains, a grain stack becomes an effective insulator.

When filling a silo with harvested grain, it's common to end up with layers of various grain moisture contents and temperatures.

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.

5.4.3 Condensation

Air in the headspace of a silo heats during the day, and cools at night creating ideal conditions for condensation to form. As illustrated in Figure 2, without aeration and ventilation, condensation can cause damp patches of grain at the top of the silo. Damp grain provides a breeding ground for insects and mould. Active insects create heat, which makes it an even more attractive breeding ground, so insects quickly multiply and spread through the grain bulk.

Aeration cooling and ventilation in storage reduces condensation and the adverse effects it creates.

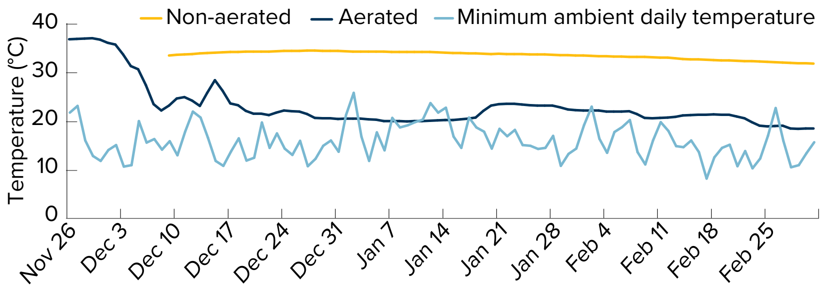


Figure 3: *Aeration cooling vs no aeration cooling*

Source: NSW DPI

5.4.4 Grain temperature targets

In the same way moisture affects the development of mould and insects, temperature also has an impact.

Storing grain at or below the delivery standard moisture content (12.5 per cent for most grains) reduces the chance of mould and insects developing, but warm or hot grain is still attractive for insects.

At cool temperatures insect pest life cycles (egg, larvae, pupae and adult) are extended from the typical four weeks at warm temperatures (30–35°C) to life cycles of 12-17 weeks at cooler temperatures (20-23°C).

While adult insects can still survive at cool temperatures, young insects stop developing at temperatures below 18-20°C. At grain temperatures below 15°C, reproduction of the five most common stored-grain insect pests stops (Table 3).

Table 3: Lower limits to reproduction

Insect	Temperature (°C)
Rice weevil	15
Bruchid — cowpea weevil	17
Lesser grain borer	18
Rust-red flour beetle	20
Saw-toothed grain beetle	20

Source: DAF, QLD

5.4.5 Aeration system design

Fan selection

Selecting the correct aeration fan is critical to achieving the required airflow. Fan performance depends not only on the fan itself, but also on factors such as grain type, grain depth, static pressure and the design of the aeration system. As a result, published manufacturer specifications may not always reflect performance under on-farm operating conditions.

Independent testing has shown that the measured performance of some aeration fans differs from published specifications. In some cases, airflow has been lower than advertised, while other fans have exceeded their published performance. Where independent test data are available, growers should use these results to compare fan performance and ensure the selected system will provide adequate airflow for the intended application.

Earlier research found that aeration airflow rates of 1-2 L/s/t were sufficient to cool grain over time. More recent research has shown that airflow rates of 2-4 L/s/t cool grain more rapidly, allow the short-term storage of grain with slightly elevated moisture content, and provide a safety margin where grain type, silo design or grain depth impose higher static pressure on the fan.

MORE INFORMATION

Grain Aeration Design and Performance Guide 2024

MORE INFORMATION

The science of cool

Aeration fans operate against the static pressure (back pressure) created by the grain bulk. In practice, this back pressure is often higher than under controlled test conditions because grain can settle during storage, increasing its bulk density. Grain type, grain depth and silo design all influence the static pressure imposed on the fan and, consequently, the airflow achieved.

Where higher airflow rates are required, multiple fans may be installed. However, the fans must be identical, and adding extra fans does not increase airflow proportionally. As airflow increases, static pressure also increases, reducing the performance of each additional fan. Observations have shown that a second fan typically increases the initial airflow by around 50%, with a third fan providing a further 30% increase. Additional fans generally provide diminishing returns, and in some situations a fourth fan was measured to deliver little additional airflow—or even reduce overall performance.

The performance of single or multiple fan installations ultimately depends on the fan's operating characteristics and the static pressure of the aeration system. This should be considered during silo design, as achieving the target airflow for aeration cooling or drying may require more than one correctly selected fan.

Different grain types create different levels of static pressure (back pressure), which directly affects aeration fan performance. Recent GRDC development activities measured the static pressure of a range of grain types at airflow rates of 1, 2, 3, 4, 10, 15 and 20 L/s/t.

Figure 4 compares the static pressure generated by different grain types at the recommended minimum aeration cooling airflow rate of 2 L/s/t over a range of grain depths. Canola, sorghum and lentils produced the highest static pressures of the grains tested. Where these crops make up a significant proportion of grain storage, their higher airflow resistance should be considered when selecting aeration fans and designing aeration systems.

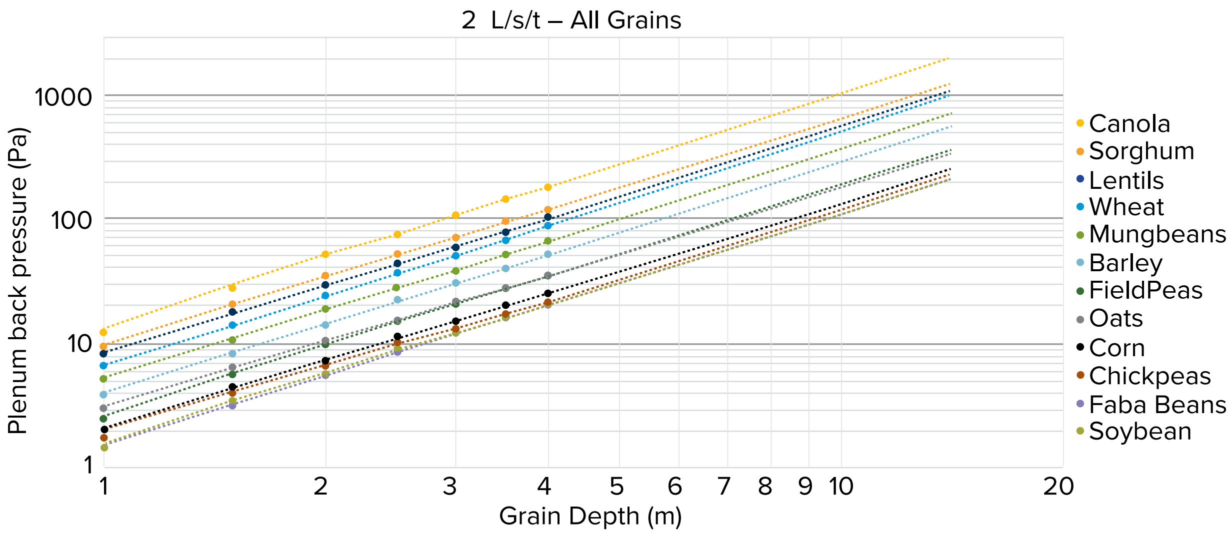


Figure 4: *Static pressure (back pressure) of consolidated (not loose-filled) grain types. Actual system static pressure will also include resistance from aeration ducting, plenums, false floors, inlet screens and other system components. These factors should be considered when selecting and designing aeration systems. Note: both axes use logarithmic scales.*

Ducting and ventilation

While aeration cooling can be achieved with relatively low airflow rates, appropriate ducting location and design to distribute air evenly through the grain stack helps prevent areas with little or no airflow.

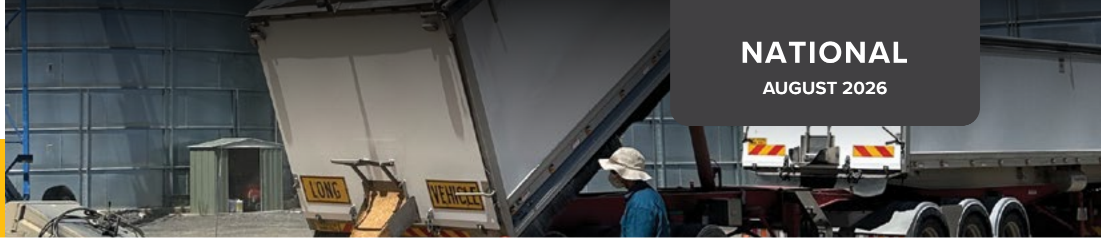
Position ducting where it will provide even air distribution throughout the storage.

In a number of cases, such as aeration systems for large silos or grain sheds, it is important to obtain professional advice on duct and vent requirements. As a general guide, full-floor or false-floor type aeration ducts provide ideal air distribution for drying. Trench-style ducts are adequate for aeration cooling and can be removed for cleaning.

Any restriction to airflow due to inadequate ducting or ventilation will create extra back pressure, which will significantly restrict fan performance, resulting in reduced airflow. Systems that require flexible ducting between the fan and the silo, or fans ducted to multiple silos significantly inhibit fan performance and air distribution.

Aeration cooling fans can be retrofitted to cone-bottom silos relatively simply and are a particularly valuable addition to silos that cannot be gas-tight sealed for fumigation. Look for a kit that is simple to install and easy to clean. (See Photo 6)

Photo 6: *When ordering aeration kits for cone-bottom silos, look for one that is simple to install and easy to clean. (Source: Chris Warrick, Primary Business)*



Hygiene in ducting

When considering ducting, what is best for aeration is often worst for hygiene. Aeration ducting collects grain dust and small particles providing an ideal environment for insect pests. Even structural treatments for insect control will not penetrate thick layers of dust in aeration ducting, so insects survive, ready to infest the next batch of grain that enters the storage.

The best solution is ducting that can be cleaned easily or removed for cleaning.

Most tubular ducting and trench-type ducts in flat-bottom silos can be cleaned thoroughly with a compressed air nozzle or industrial vacuum cleaner, but a full-floor perforated air plenum in a flat-bottom silo is impossible to clean properly.

Silos have various systems for cleaning in-floor ducting and plenums, but the most thorough system is a floor with removable sections to allow access for cleaning. (See Photo 7).

For more information on hygiene around grain storages, see Section 5.1 Hygiene.

MORE INFORMATION

Note: If aeration cooling is being used to hold moderately high-moisture grain (up to 15 per cent moisture content for wheat or sorghum) temporarily until drying equipment is available, run fans continually while the ambient relative humidity is below 85 per cent. Balance this with not leaving fans off for extended periods during the first few days of storage. Airflow of 3-4 L/s/t is required.

MORE INFORMATION

Note: Some automatic aeration controllers with a relative humidity override will not stop the fans if it is set on ‘manual’ or ‘continuous’ mode and may need to be set to a setting such as ‘auto continuous’.

FAQ

5.4.6 The cooling process

Aeration cooling is one of the most effective tools for maintaining grain quality during storage. Correctly designed and operated aeration systems reduce grain temperature, suppress insect activity, maintain seed vigour and grain colour, and extend safe storage life. However, the effectiveness of aeration cooling depends on ambient conditions and correct system operation.

Once grain has reached a suitable storage moisture content, aeration cooling can begin. While reducing grain temperature is the primary objective, the temperature achieved is influenced not only by the ambient air temperature but also by its relative humidity. Together, these factors determine the equilibrium temperature and moisture relationship between the grain and the surrounding air.

Table 4 illustrates the effect of relative humidity on the equilibrium grain temperature. For example, grain at 12% moisture content cooled using ambient air at 25°C will reach an equilibrium temperature of approximately 20°C when the air is 30% relative humidity, but around 28°C when the relative humidity is 75%. Because both temperature and humidity influence aeration performance, wet-bulb temperature, which combines these two factors, provides a useful indicator of how ambient air will interact with stored grain.

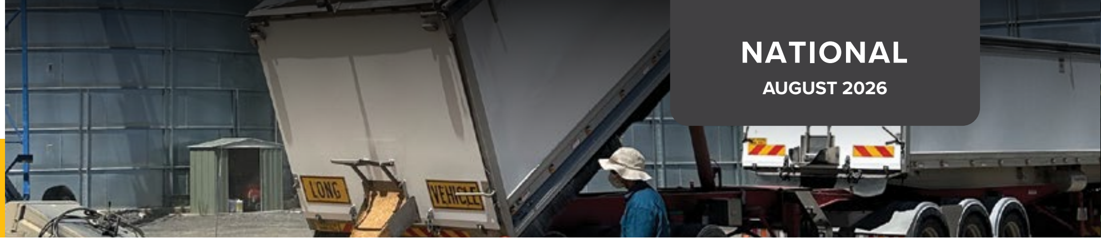
The process of aeration cooling occurs in three stages: continuous cooling, rapid cooling and maintenance cooling.

Stage one — continual aeration

The initial objective of aeration cooling is to maximise airflow through the grain bulk as soon as possible after harvest. This establishes the first cooling front, rapidly reducing grain temperature and slowing insect activity. Without aeration cooling, freshly harvested grain will often continue to increase slightly in temperature after it is placed into storage.

Once the grain has covered the aeration ducts, operate the aeration fans continuously for up to five days, or until the smell of the air exiting the top of the silo changes from warm and humid to cool and fresh. The time required for the initial cooling front to pass through the grain will vary depending on storage size, grain depth and airflow rate.

Avoid operating aeration fans continuously during periods when the ambient relative humidity exceeds 85 per cent as moist air may increase grain moisture around the aeration ducts and promote mould development. Automatic aeration controllers are designed to switch fans off above around 85 per cent relative humidity.



VIDEOS

Utilising aeration cooling in grain storage

Aeration cooling – too selective too soon

FAQ

Stage two — rapid cooling

After aeration fans have been running continuously to flush out the warm, humid air, reduce run time to 9–12 hours per day for the next 7 days. The difficulty is selecting the coolest air to run the fans and being on site to turn the fans on and off.

Automatic aeration controllers that use time proportioning control (TPC) call this phase 'rapid' or 'purge'. During this stage they are programmed to run fans during the coldest 12 hours of each day. The goal is to quickly reduce the grain temperature from the mid 30°Cs to the low 20°Cs.

An initial reduction in grain temperature of 10°C ensures grain is less prone to damage and insect attack, while further cooling becomes a more precise task.

Stage three — maintenance cooling

After the 'rapid' or 'purge' phase TPC automatic controllers are then switched to 'normal' or 'protect' mode. During this final phase they continually monitor ambient conditions and run fans on average during the coolest 100 hours per month.

Operating fans without a controller is a lot more difficult, but the aim is to select the coolest air, providing it is below 85 per cent relative humidity, and running fans, on average, for a total of 100 hours per month.

This rule-of-thumb run-time may vary from week to week with weather cycles and automatic controllers often won't run fans for up to 7–10 days. The controller may then take advantage of a cool change in the weather, running fans for up to 48 hours to catch up.

Table 4: The relationship between air temperature and relative humidity and grain moisture content

Inlet air		Resulting temperatures in wheat at varying moisture contents (°C)		
Temperature (°C)	Relative humidity (%)	10	12	14
15	30	15	12	10
	45	17.5	14	12
	60	20	16	13.5
	75	22	18	15.5
20	30	20	16	13.5
	45	22.5	18.5	16.5
	60	25	21	18.5
	75	27.5	23	21
25	30	24	20	17.5
	45	27	23	20.5
	60	30	25.5	23.5
	75	32.5	28	25.5
30	30	28	24	22
	45	31.5	27	25
	60	34.5	30.5	28
	75	37.5	33	30.5

Source: DAF, QLD

Photo 7: *In-floor aeration ducting in flat-bottom silos, which can be removed for cleaning, is ideal. (Source: Chris Warrick, Primary Business)*

5.4.7 Automatic controllers for cooling

For the purposes of aeration cooling, automatic controllers are by far the most effective and most efficient method of control. Not only will they cool grain quickly and efficiently, they all have trigger points to turn fans off if ambient conditions exceed 85 per cent relative humidity.

Automatic aeration controllers for cooling are available in four main variations:

- Set-point controllers
- Time Proportioning Controllers (TPCs)
- Adaptive Discounting Controllers (ADCs)
- Internal sensing controllers.

Set-point controllers

The set-point controller requires the operator to select a specified temperature and relative humidity that will trigger fan operation. As time passes these set points need to be manually adjusted to allow for more precise cooling.

Set-point controllers are generally at the lower end in price and in turn provide a lower level of automation and control. Be aware that the relative humidity sensors used in lower cost controllers may not be accurate above 75 per cent relative humidity, risking inaccurate switching and moisture introduction which could cause mould.

Time proportioning controllers (TPCs)

Put simply, TPCs monitor ambient conditions and use algorithms to operate like a self-adjusting thermostat.

They continually recalculate a trigger point to select the coolest part of the day to run fans. The unique feature is that the moving trigger point means fans may not run for several days if conditions are warm, but will then run continuously for several hours, even days, to take advantage of a cool change. These controllers are generally well balanced in price, performance and usability for on-farm storages.

Adaptive discounting controllers (ADCs)

Adaptive discounting controllers rely on the operator entering all the parameters of the storage, aeration capacity, quantity of grain, grain moisture and temperature and the grain moisture and temperature targets. The ADC then monitors the ambient conditions and runs the fans at times when the ambient conditions are calculated to get the grain closer to the target temperature.

These controllers rely on the storage, aeration system and grain parameters being entered accurately at every fill, in order to be effective.

Internal sensing controllers

Internal sensing controllers use sensors inside the storage and compare them with ambient conditions. If the difference in ambient to internal conditions will get the grain closer to its target temperature, then the controller turns the fans on.

Internally sensing controllers are generally suited to high-value products or aeration drying silos. They are usually at the higher end of the pricing scale and have the highest cost of installation, but in turn are expected to have superior performance.

If considering a controller with internal sensors, ensure a fail-safe or alert system notifies the operator if there's an issue with one of the sensors or communication to it.

Photo 8: *At grain temperatures below 15°C most storage pests stop reproducing. (Source: Chris Warrick, Primary Business)*

5.4.8 Monitoring is key

Regular monitoring of both ambient conditions and grain temperature is essential to assess aeration performance and identify developing storage problems before they become serious. Monitoring grain temperature confirms that aeration cooling is operating effectively and helps detect localised heating caused by insect activity, mould or moisture migration.

Grain temperature also influences the effectiveness of phosphine fumigation. As grain temperature decreases, insect metabolism slows and phosphine acts more slowly, requiring longer exposure periods. Grain temperature should therefore be considered when planning fumigation and determining the required exposure time.

5.4.9 Airflow distribution within silos

Understanding how air moves through the grain bulk is critical to achieving effective aeration cooling. Airflow distribution changes as grain settles during storage and again when grain is removed from the silo. As a result, the depth and profile of the grain surface have a significant influence on the path of least resistance for airflow.

Research has shown that airflow distribution is strongly influenced by the shape of the grain surface, whether it is convex, concave or intermediate. These differences can create areas of relatively high and low airflow within the grain bulk, affecting cooling performance and grain quality. This is an important consideration if using aeration cooling to temporarily hold over-moisture grain.

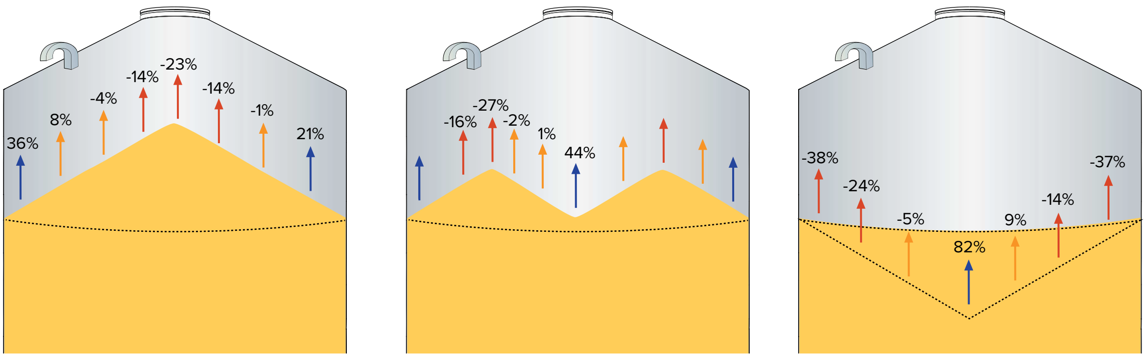


Figure 5: *Percentage variation from the average airflow rate measured throughout the grain bulk with varying surface profiles. Positive values indicate areas receiving above-average airflow, while negative values indicate areas of reduced airflow and increased storage risk.*

Areas with greater grain depth—such as the peaked centre of a convex grain surface or adjacent to the walls of a concave grain surface—receive less airflow than shallower areas. These low-airflow zones cool more slowly and are therefore at greater risk of elevated grain temperatures, insect reproduction and mould development. Airflow at the deepest point of the grain bulk can be substantially lower than the average, while shallower areas may receive considerably more airflow. Although full-floor aeration systems are often assumed to provide uniform airflow, recent testing has shown that grain surface profile and grain depth continue to have a significant influence on airflow distribution.

Aeration key recommendations

- Select aeration fans based on independently verified performance data wherever possible. Published fan specifications may differ from performance achieved under on-farm operating conditions.
- Match the aeration system to the storage. Fan selection should consider silo type, grain type, grain depth and the expected static pressure to ensure adequate airflow is achieved.
- Monitor grain and ambient conditions regularly. Routine monitoring of grain temperature, ambient conditions and fan operation confirms aeration performance and enables developing problems to be identified early. Incorporate grain monitoring into routine storage hygiene and maintenance inspections.
- Manage grain surface profiles. The shape of the grain surface influences airflow distribution within the grain bulk. Where practical, minimise excessive peaks and hollows during filling and pay particular attention to monitoring areas of greater grain depth where airflow is reduced.

Photo 9: *Ensure manufacturer quoted airflows have been field tested. Research has identified variation between theoretical and actual fan performance. (Source: Chris Warrick, Primary Business)*

MORE INFORMATION

Insect resistance testing contact details

Managing insect pests in stored grain

The tolerance for live insects in grain marketed off-farm is nil.

As more grain is stored on Australian farms, an integrated approach to pest management is essential to maintain grain quality and market access.

Five integrated management practices underpin effective stored-grain quality maintenance and pest prevention:

- Meticulous grain hygiene
- Structural treatments
- Aeration cooling
- Protectants (where suitable)
- Regular monitoring.

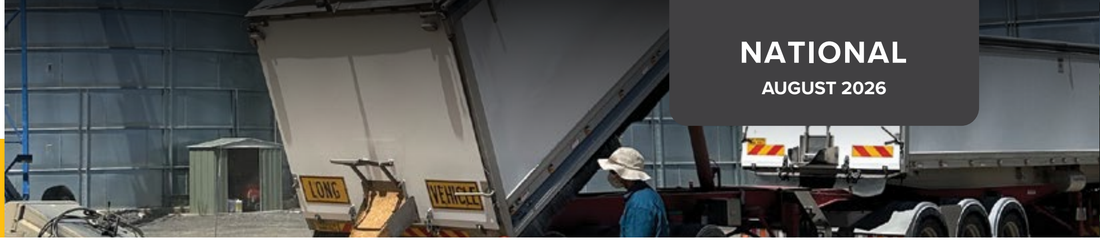
When best efforts to prevent insect infestations fail, or grain receival requirements demand it, fumigation in a gas-tight storage is necessary.

The two principal fumigants used for on-farm grain storage are phosphine and sulfuryl fluoride. Phosphine is the most widely used fumigant because it is cost-effective and registered for all major grain types grown in Australia. However, increasing levels of phosphine resistance have highlighted the importance of resistance management. Some growers now engage licensed commercial fumigators to apply sulfuryl fluoride as part of an integrated resistance-management strategy.

Both phosphine and sulfuryl fluoride require gas-tight storage to achieve effective control of all insect life stages. While phosphine is registered for all major cereal grains, sulfuryl fluoride is not registered for pulses or oilseeds intended for human consumption (at the time of publication).

Grain temperature should also be considered when planning fumigation. Phosphine remains effective at grain temperatures down to approximately 15°C, although longer exposure periods are required when the grain is below 25°C. Sulfuryl fluoride remains effective at temperatures down to approximately 20°C.

A highly phosphine-resistant strain of flat grain beetle (*Cryptolestes ferrugineus*), sometimes referred to as the rusty grain beetle, has been identified in Australia. If insects survive a correctly applied phosphine fumigation, collect a sample for resistance testing and consider refumigation with sulfuryl fluoride, another registered fumigant, or a controlled-atmosphere treatment. Contact your nearest resistance testing laboratory using the link opposite.



6.1 Fumigating with phosphine

Phosphine remains the most widely used fumigant for controlling stored-grain insects in Australian grain production systems. However, incorrect use continues to reduce its effectiveness and is contributing to the development of resistance in several key stored-grain pest species (Figure 1).

A GRDC survey conducted in 2024 found that only 58 per cent of growers using phosphine applied it correctly in a gas-tight, sealed silo, highlighting the need for improved fumigation practices.

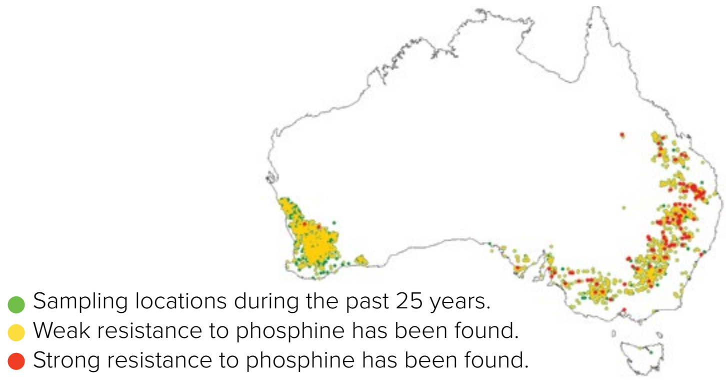


Figure 1: *Phosphine resistance – National situation*

Source: DPIRD

Taking shortcuts with fumigation may kill enough adult insects for grain to appear pest free at delivery, but it will not eliminate all life stages of stored-grain insects. More importantly, poor fumigation practices accelerate the development of phosphine resistance, reducing the long-term effectiveness of Australia's most important grain fumigant.

To achieve complete control of stored-grain pests—including eggs, larvae, pupae and adults—phosphine must reach and maintain a lethal concentration for the required exposure period. This can only be achieved in a pressure-tested, gas-tight storage.

Poor fumigation practices fail to kill pests at every life stage. Although some adult insects may be controlled, surviving eggs and larvae will quickly reinfest the grain. Each ineffective fumigation also selects for insects with greater phosphine tolerance, increasing the prevalence of resistant populations over time.

Using the correct storage is therefore the first and most important step towards effective fumigation. Always fumigate grain in a pressure-tested, gas-tight silo. Research has consistently shown that storages that are not gas-tight cannot maintain a lethal phosphine concentration for long enough to achieve complete control of all insect life stages.

VIDEOS

Get gas-tight storage

MORE INFORMATION

Phosphine best management practices: Disinfesting stored commodities

Photo 1: *Correct phosphine use in pressure-tested, gas-tight storages is essential for controlling stored-grain pests and slowing the development of phosphine resistance. (Source: DPIRD)*

Plan, monitor and control for clean grain

- Dispose of grain residues and seed gradings. Clean empty storages and grain handling equipment, including harvesters, field bins and augers.
- Apply structural treatments to empty storages and grain handling equipment.
- Sieve stored grain for the presence of insects at least monthly, and use probe traps. Also check grain temperature and moisture.
- If grain temperature has been kept below 20°C by well-managed aeration cooling, insect numbers are likely to be low.
- Sample grain 3-4 weeks before sale to allow time for any fumigation treatment.
- For effective fumigations, pressure test sealable silos at least once a year to identify any leaks and maintain rubber seals.
- The phosphine fumigation process typically requires 10–17 days so allow enough time before out-loading. (27 days in large storages without recirculation and longer in grain bags with only passive venting).

6.1.1 Control all life stages

To control stored-grain pests at all life stages and minimise the development of phosphine resistance, the phosphine concentration during a fumigation must reach **550 parts per million (ppm)** and remain above this level for the required exposure period. At grain temperatures above **25°C**, a minimum exposure period of seven days is required. Between **15°C** and **25°C**, the exposure period should be extended to 10 days. As grain temperature decreases, insect metabolism and development slow, requiring a longer exposure period to achieve a lethal dose at all life stages.

Fumigation trials have shown that even small leaks can dramatically reduce phosphine concentrations within a silo. In storages with minor leaks, phosphine concentrations as low as 3 ppm have been recorded as the maximum achieved adjacent to leak points. Gas concentrations throughout the remainder of the silo are also reduced, preventing lethal concentrations from being maintained for the required exposure period.

Figure 2 illustrates phosphine concentrations achieved in a 130 t pressure-tested, gas-tight silo with a 3.5-minute pressure half-life. The required concentration of 550 ppm is reached at the top and middle of the silo within the first day and at the bottom by the second day. Concentrations then remain well above 550 ppm for the required seven-day exposure period.

In contrast, Figure 3 shows phosphine concentrations in a 130 t silo with two minor leaks. Although concentrations at the top of the silo briefly exceed 550 ppm, they remain above this threshold for only four days, well short of the required exposure period. Concentrations in the middle of the silo never reach 550 ppm, while concentrations near the base remain extremely low (0-3 ppm) and are insufficient to control stored-grain pests.

The poor gas distribution shown in Figure 3 resulted from just two small leaks—one near the roof and one near the base of the silo. This demonstrates how even minor leaks can prevent phosphine from reaching and maintaining lethal concentrations throughout the grain bulk.

Figure 3 shows that in a 130 t silo with minor leaks (not gas-tight) phosphine gas concentrations do not reach the required concentration level, for the necessary period, to kill pests at all life stages.

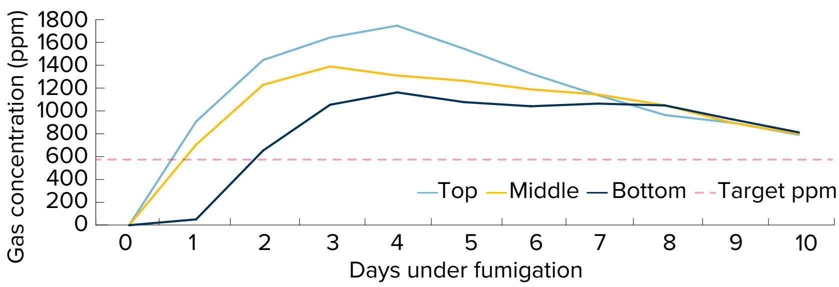


Figure 2: *Gas concentration in a gas-tight silo (3.5 minute half-life pressure test).*

Source: DAF, QLD

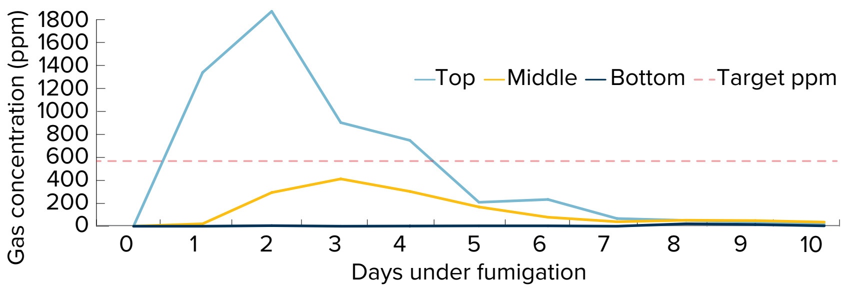
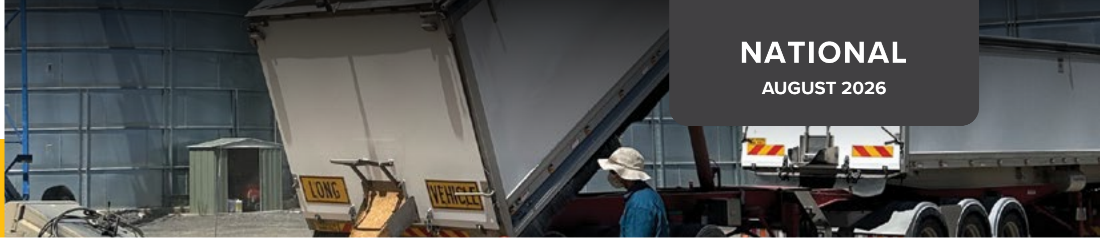


Figure 3: *Gas concentration in a non-gas-tight silo (8 second half-life pressure test).*

Source: DAF, QLD

Poor fumigations may appear successful because some adult insects are killed, but many eggs, larvae and pupae survive and later reinfest the grain.

These partial kills are often worse than no kill at all because the surviving insects are more likely to carry phosphine resistance genes. Every ineffective fumigation increases the proportion of resistant insects in the population, reducing the effectiveness of phosphine for the entire grains industry.



MORE INFORMATION

[Kondinin Group: Grain Silos Research Report]

Storage choices

When purchasing a new silo, choose a quality, gas-tight, sealable silo fitted with aeration cooling. Confirm with the manufacturer that it complies with the Australian Standard for sealable silos, AS2628–2010.

The Australian Standard was developed in response to industry concerns that poorly sealed storages were failing to maintain phosphine concentrations for long enough to control all insect life stages. These ineffective fumigations have been a major contributor to the development of phosphine resistance in stored-grain pests.

To comply with AS2628–2010, a new silo must achieve a minimum five-minute pressure half-life. During the pressure test, the oil level in the pressure-relief valve must take at least five minutes to fall from a 25 mm to 12.5 mm differential, demonstrating that the silo is sufficiently gas-tight for effective fumigation.

The standard provides growers with an industry benchmark when comparing sealable silos. Ask the manufacturer or reseller to state compliance with AS2628–2010 on the invoice and insist the silo successfully passes a five-minute pressure half-life test at installation or on completion of construction.

Experience has shown that having at least two gas-tight, sealable, aerated silos on-farm provides the flexibility to batch fumigate grain while maintaining an efficient grain out-loading and delivery program.

Many older silos were not designed to be gas-tight and are therefore unsuitable for phosphine fumigation. However, retrofitting these storages with aeration cooling can significantly reduce insect development by lowering grain temperature and improving grain quality during storage.

For more information on selecting a suitable grain storage system, refer to Section 1 – Grain storage: Planning and purchasing.

VIDEOS

Grain Storage Series: Pressure testing silos

6.1.2 Pressure testing sealable silos

Pressure testing confirms that a silo is sufficiently gas-tight to maintain phosphine concentrations required to kill stored-grain insects at all life stages. A silo marketed as 'sealed' is not necessarily suitable for fumigation. The only way to verify a silo is gas-tight is by conducting a pressure half-life test.

The term 'sealed' has historically been used to describe silos that simply keep out rain and dust, rather than those capable of retaining fumigant gas. A silo should only be considered gas-tight if it passes the five-minute pressure half-life test specified in AS2628–2010. Many silos sold as sealed do not meet this standard and are therefore unsuitable for phosphine fumigation.

Even silos that complied with the Australian Standard when new will gradually deteriorate as seals, gaskets and fittings wear. Regular inspection, maintenance and pressure testing are therefore essential to ensure the silo remains suitable for fumigation.

VIDEOS

Good reason to pressure test silos before fumigating

Pressure testing is quick to perform and should be carried out at three key times:

1. When a new silo is installed. Pressure test the silo before accepting delivery or making final payment to confirm it complies with AS2628–2010.
2. Before every fumigation. If the silo contains grain, repeat the pressure test immediately before fumigation. This is particularly important for cone-bottom silos, where the weight of grain can affect slide-plate outlet seals.
3. As part of annual maintenance. Empty silos provide the best opportunity to inspect, replace seals and repair leaks before the next storage season.

Start a pressure test with equal oil levels on the middle marker.	Pressurise silo to create a difference in oil levels of 25 mm.	The time taken for the oil levels to drop from 25 mm apart to 12.5 mm apart must be no less than five minutes on new silos. For older silos, three minutes is acceptable.

Photo 2: *Pressure testing a gas-tight, sealable silo confirms it is suitable for effective phosphine fumigation. To comply with Australian Standard AS2628–2010, the silo must achieve a five-minute pressure half-life test (left to right). (Source: Chris Warrick, Primary Business)*

Carrying out a pressure test

1. Choose the right conditions

Select a time when ambient conditions are stable. The best time to pressure test a silo is before sunrise or on an overcast day, when the sun is not heating the silo.

As the silo warms during the day, the air inside expands. Conversely, cooling from falling temperatures, cloud cover or wind causes the air to contract. These changes can influence the pressure inside the silo and produce misleading test results.

Pressure testing should therefore only be undertaken when ambient temperatures are relatively stable.

2. Check seals

Before commencing the test, inspect all seals, including the roof lid, access hatch, outlet and aeration fan seal. Ensure all lids and access hatches are fully closed and securely latched.

3. Install an air valve

The simplest method of pressurising a silo is with a battery-powered leaf blower.

A 50 mm ball valve permanently fitted to the silo, or an adaptor that allows the valve to be connected to the passive recirculation pipe, provides a convenient way to pressurise the silo before closing the valve to begin the test.

VIDEOS

GCTV2: Pressurising a silo

VIDEOS

On-farm Grain Storage: Pressure relief valves

VIDEOS

Oil for pressure relief valves

4. Check oil levels

Pressure-relief valves should be filled with a light hydraulic oil such as ISO 46 or ISO 32. These oils provide suitable viscosity for pressure relief while resisting evaporation and contamination.

Some sealable silos do not have an easily visible oil pressure-relief valve. In these situations, consider one of the following options:

- replace the pressure-relief valve with a more visible design
- construct a simple manometer using clear tubing
- use a digital or analogue manometer.

Before pressurising the silo, confirm the oil level is equal on both sides of the gauge and aligned with the centre reference mark (Photo 3).

If the reference marks are difficult to see, clearly re-mark the gauge to indicate:

- fill level
- 25 mm differential
- 12.5 mm differential

Remember that a 25 mm differential means the oil rises 12.5 mm on one side of the gauge and falls 12.5 mm on the other. A 12.5 mm differential therefore represents approximately 6.25 mm above and below the level mark on each side.

Photo 3: *Ensure the pressure relief valve is filled with sufficient oil to be level with the middle indicator mark. (Source: Chris Warrick, Primary Business)*

5. Pressurise the silo

Before pressurising the silo, confirm the oil levels remain stable for several minutes after all openings have been sealed. This confirms that changing ambient conditions are not influencing the pressure inside the silo.

Using a battery-powered leaf blower, or a small aeration fan if fitted, pressurise the silo until the oil levels in the pressure-relief valve are more than 25 mm apart or the valve begins to bubble. This typically takes only a few seconds in a cone-bottom silo, one to two minutes in a large flat-bottom silo, and several minutes in a full flat-bottom silo.

As soon as the oil levels exceed a 25 mm differential, or bubbling occurs, stop the blower or fan immediately and seal the air inlet by closing the ball valve or fan inlet.

Do not use large aeration fans to pressurise the silo, as they can generate excessive pressure and damage the silo structure or seals.

VIDEOS

[On-farm Grain Storage: Silo maintenance]

VIDEOS

[Grain Storage Series: When to seal silos]

VIDEOS

[Sealing silos for fumigation – clamp style outlet seal tip]

6. Time the half-life

Start the timer when the oil levels reach a 25 mm differential (aligned with the upper and lower reference marks). The time taken for the oil level differential to fall from 25 mm to 12.5 mm (halfway back to level) must be no less than five minutes for a new silo to comply with AS2628–2010. This procedure is known as the pressure half-life test.

On a digital or analogue manometer, a 25 mm oil differential is equivalent to 250 Pa, while the 12.5 mm half-life point corresponds to 125 Pa.

Although field experience has shown that older silos achieving a three-minute pressure half-life can often be fumigated successfully, all new sealable silos should comply with the Australian Standard requirement of a five-minute pressure half-life.

7. Looking for leaks

If the pressure half-life test fails, the silo has one or more leaks that must be repaired before it can be used for fumigation.

To locate leaks, pressurise the silo again and spray soapy water around all seals, joins and fittings. Escaping air will produce bubbles, making leaks easy to identify.

Common leak locations include:

- bottom outlet
- aeration fan inlet seal
- roof lid and access hatch seals
- bent or damaged lids
- stretched or poorly adjusted latch springs
- wall, roof and base joins.

Some cone-bottom silos rely on the slide plate outlet to provide the seal rather than using a dedicated gasket. These outlets may require clamping before filling. In some designs, the weight of grain can distort the slide plate, preventing the outlet from sealing properly. Once grain has been discharged, the outlet may not reseal until the silo is completely emptied.

Older silos may require more extensive maintenance, including replacing seals, adjusting latches and repairing joints, to restore a gas-tight seal.

Once repairs have been completed, repeat the pressure half-life test to confirm the silo now meets the required standard.

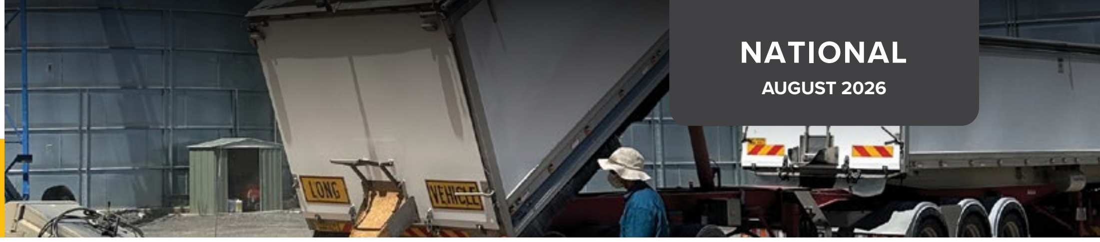
When to seal silos

Gas-tight, sealable silos are designed to remain sealed only during the fumigation exposure period. At all other times they should be left unsealed so the silo can breathe.

Allowing the silo to breathe enables pressure to equalise with changing ambient conditions and reduces the risk of condensation forming in the headspace, helping prevent mould development.

As ambient temperatures rise and fall, the air inside the silo expands and contracts. If the silo is left sealed, these daily pressure changes place unnecessary stress on the pressure-relief valve, seals and silo joints, reducing their service life.

Pressure-relief valves are designed to open when the pressure difference reaches approximately 500 Pa, allowing the silo to breathe and equalise with the surrounding atmosphere. Leaving a silo sealed unnecessarily causes the valve to cycle more frequently, increasing wear on the valve and the silo seals.



6.1.3 Phosphine safety — handle with care

After a silo has been pressure tested and satisfied the half-life pressure test of five minutes for a new silo or three minutes for an older silo, it can then be used as a fumigation chamber for phosphine.

Phosphine is a highly toxic gas with potentially fatal consequences if handled incorrectly. Phosphine is classed as a schedule seven poison, which is indicated on the label — DANGEROUS POISON.

As a minimum requirement, the label directs the use of elbow-length PVC gloves and a full face breathing-respirator with combined dust and gas cartridge. The combined dust and gas cartridge (canister) must be suitable for phosphine, often listed as an inorganic gas. Be aware that cartridges have a limited lifespan as they contain activated carbon. After use, store cartridges in a sealed container and follow manufacturer directions for replacement. Wash mask and gloves with warm water and detergent after each day's use.

Working with phosphine in an open, well-ventilated area with the wind coming from the side will help carry the gas away from the body.

VIDEOS

Masks for phosphine

SAFETY TIP

Avoiding explosion

Phosphine containers must only be opened outdoors. When opening containers take care and point container lids away from the face and body. Under rare conditions, a build-up of gas inside the container is possible, and can result in flash flame upon exposure to air.

When opened, use the entire contents — do not reseal left-over tablets. After a container has been opened and exposed to ambient air carrying moisture, the phosphine tablet starts evolving into gas as it reacts with moisture in the air. If the lid is replaced, gas inside the tin continues to be released and can reach spontaneous flammability levels if it builds up to 17,900 ppm.

MORE INFORMATION

Respirators and filters for phosphine fumigations

Personal exposure limits

At the time of printing, new Safe Work Australia Workplace Exposure Standards for airborne contaminants are scheduled to take effect on 1 December 2026.

For phosphine, the short-term exposure limit (STEL) of 1 ppm has been replaced with a peak exposure limit of 0.15 ppm. The time-weighted average (TWA), measured over an eight-hour working day and 40-hour working week, has been reduced from 0.3 ppm to 0.05 ppm.

Always refer to the current Safe Work Australia Workplace Exposure Standards for the latest exposure limits and compliance requirements (see link opposite).

For the latest research findings and practical guidance on managing these changes, refer to the current phosphine fumigation guide (see link opposite).

Importantly, the odour threshold of phosphine is approximately 2 ppm for those who can detect its characteristic smell. This is well above both the current and forthcoming workplace exposure limits, meaning that by the time phosphine can be smelled, the concentration has already exceeded safe exposure levels. Never rely on smell to detect the presence of phosphine gas.

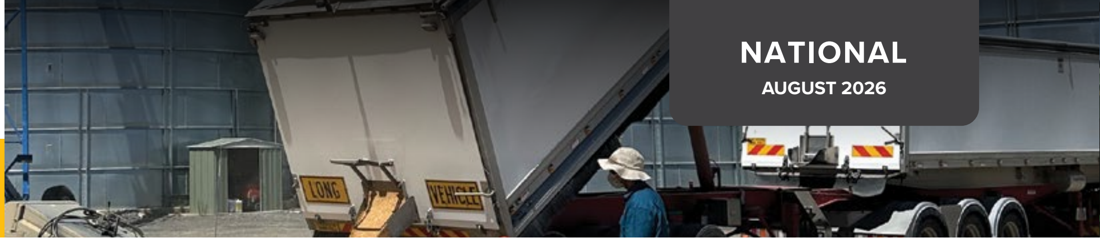
Never rely on the odour of phosphine to determine if the atmosphere is safe.

Always read the product label and Material Safety Data Sheet (MSDS) for safety information and required PPE.

MORE INFORMATION

Workplace exposure limits for airborne contaminants

The current guide for phosphine fumigation



VIDEOS

Phosphine meters

MORE INFORMATION

Grain Storage management equipment (Phosphine meters, sign suppliers and other safety equipment)

6.1.4 Electrical equipment

Phosphine is corrosive to copper so any equipment such as switches, meters or sensors with exposed copper should be removed from the silo or sealed before fumigating.

Personal monitors raise the alarm

Personal phosphine monitors are readily available and simple to use. Worn on the operator's collar within the breathing zone, they continuously monitor phosphine concentrations and provide audible and visual alarms as gas concentrations approach workplace exposure limits.

Because these monitors are used to detect phosphine at very low concentrations, accuracy is critical. In accordance with Australian Standards and manufacturer recommendations, personal phosphine monitors should be calibrated at least every six months. Ensure equipment suppliers or service agents configure alarm thresholds to comply with the current Safe Work Australia Workplace Exposure Standards.

While the purchase cost may deter growers who only fumigate occasionally, personal phosphine monitors provide an important layer of protection against accidental exposure and should be given serious consideration.

Many low-range phosphine monitors can also be used to confirm phosphine concentrations have fallen to safe levels at the end of the venting period, to ensure grain is safe to out-load and complies with clearance requirements set by delivery sites.

SAFETY TIP

Photo 4: *Personal phosphine monitors sound an alarm if harmful concentration levels are detected. (Source: Chris Warrick, Primary Business)*

6.1.5 Phosphine application

Phosphine is available in three different forms for on-farm use (bag chains, blankets and tablets) and there are various ways to apply each option effectively in a gas-tight, sealed silo.

Bag chains contain the tablets and residue in a chain of pockets, negating the risk of powder residues spilling into grain or onto the operator.

The traditional and most recognised form is tablets, which can be bought in tins of 100 or 500.

The other form — phosphine blankets — is designed for bulk storages larger than 600 tonnes such as flat-bottom silos.

Phosphine application rates are based on the internal volume of the gas-tight, sealable storage—not the amount of grain it contains. Regardless of how much grain is in the silo, the phosphine dose remains the same because it is calculated on the total internal volume of the storage.

As the application rate does not change, it can be useful to permanently mark the required phosphine dose on the silo.

Some manufacturers recommend that silos are at least two-thirds or three-quarters full before fumigation. The rationale is that silos containing a large headspace are more susceptible to pressure changes caused by daily temperature fluctuations. This results in more frequent operation of the pressure-relief valve, increasing air exchange and potentially reducing phosphine concentrations during the fumigation period. Larger pressure fluctuations may also place additional stress on the silo structure and seals.

VIDEOS

Fumigation timing for stored grain

VIDEOS

The fumigation process in grain storages

Using bag chains

Bag chains are available in two sizes: 340 g chains, which liberate 114 g of phosphine and are suitable for up to 75 m^3 (approximately 60 t of wheat storage capacity), and 680 g chains, which liberate 228 g of phosphine and are suitable for up to 150 m^3 (approximately 120 t of wheat storage capacity). Always refer to the product label to confirm the correct application rate.

Never cut a bag chain or retain part of it for later use. Once the packaging is opened, the phosphine formulation begins liberating gas. Storing partially used bag chains reduces their effectiveness and creates a significant phosphine exposure hazard.

Photo 5: *Bag chains reduce the risk of phosphine residue being spilled during application. However, at least 1% of the formulation remains unevolved until exposed to moisture, so a respirator and appropriate PPE must be worn when applying, removing and deactivating bag chains. (Source: Chris Warrick, Primary Business)*

Using phosphine blankets

For larger gas-tight, sealable storages, phosphine blankets may be the most practical application method. Like bag chains, blankets must not be cut or divided.

Blankets are supplied in 3.4 kg packs containing two 1.7 kg blankets. Each 1.7 kg blanket liberates 568 g of phosphine, providing sufficient fumigant for 380 m^3, or approximately 300 t of wheat storage capacity. Always refer to the product label to confirm the correct application rate.

Using tablets

The phosphine application rate is 1.5 g/m^3 of storage volume. Each 3 g tablet liberates 1 g of phosphine, equating to three tablets per 2 m^3 of silo volume.

Using a typical wheat bulk density of 1.3 m^3/t, this equates to two tablets per tonne of wheat storage capacity.

Phosphine tablets are available in tins containing 100 or 500 tablets. A 100-tablet tin liberates 100 g of phosphine and is suitable for fumigating up to 67 m^3, or approximately 50 t of wheat storage capacity.

A 500-tablet tin liberates 500 g of phosphine and is suitable for up to 333 m^3, or approximately 250 t of wheat storage capacity. Always refer to the product label to confirm the correct application rate.

Photo 6: *Phosphine tablet packs. Left: 100 tablet tin (300 g) suitable for 50 t of wheat storage capacity. Right: 500 tablet tin (1.5 kg) suitable for 250 t of wheat storage capacity. (Source: Ben White, Kondinin Group)*

Photo 7: *Phosphine bag-chain and blanket packs. Left: Bag chain (340 g) suitable for 60 t of wheat storage capacity. Right: Blankets 1.7 kg x 2 (total 3.4 kg) suitable for 600 t (or 2 x 300 t) of wheat storage capacity in silos. (Source: Ben White, Kondinin Group)*

Fumigating bunkers

Bunkers must be carefully prepared with both a base tarp and a cover tarp that are stitched and glued, heat-sealed or securely clamped at all joins to achieve an effective gas-tight seal.

Unlike gas-tight silos, bunkers cannot be pressure tested. Instead, high-range phosphine monitors should be used throughout the fumigation period to confirm phosphine concentrations remain above the required level for the specified exposure period. Research indicates this reduced application rate does not maintain adequate phosphine concentrations over time to reliably control all insect life stages. Engaging a licensed fumigation contractor to apply cylinder phosphine is an alternative option.

The product label for phosphine bag chains and blankets specifies an application rate of 0.6 g/m^3 for well-sealed bunkers greater than 1000 t capacity, with a 20-day exposure period.

After fumigation, vent the bunker in accordance with the product label. As a minimum, allow 2-5 days of venting with continuous through-flow ventilation (wind) or test with a low range phosphine meter before handling or delivering grain.

VIDEOS

GCTV: Grain bags – Fumigation

Fumigating grain bags

Fumigation of grain bags has been proven in Australia, provided the correct application and venting procedures are followed. Successful fumigation depends on the integrity of the bag remaining uncompromised throughout the exposure period, together with the use of a high-range phosphine meter to monitor gas concentrations during fumigation and a low-range phosphine meter to confirm clearance after venting.

Trials have shown that phosphine application points should be spaced no more than 7 m apart along the grain bag. The phosphine should be inserted in a manner that allows the bag to be resealed for fumigation and the application device removed afterwards to avoid contaminating the grain with spent phosphine residue. One-metre lengths of PVC pipe, with a series of 1 mm slots cut along their length and inserted horizontally into the grain, have been shown to provide even gas distribution over a 10-day exposure period.

Several venting methods have been successfully evaluated. Active venting involves propping open the discharge end of the grain bag and placing the suction side of a fan at the opposite end to draw phosphine from the bag. A passive alternative uses 50 mm slotted PVC pipes inserted every 7 m along the bag on alternating sides, with the pipe ends left open once the phosphine application devices have been removed.

Where a phosphine clearance level of 0.3 ppm is required, active venting with a fan typically requires two or more days, while passive venting may require 35 days or longer, depending on ambient conditions.

Another option is to engage a licensed commercial fumigator to treat grain bags using sulfuryl fluoride, which can be vented in less time using either the active or passive methods outlined above.

Application in the headspace

Hang phosphine bag chains in the headspace, or lay them flat across the top of the grain, to ensure air can circulate freely around the bags as phosphine gas is liberated. Tether bag chains inside the silo so they can't slide down the grain surface and become irretrievable.

Spread phosphine tablets evenly in shallow trays before placing them in the headspace of a gas-tight, sealed silo.

Maximise the surface area exposed to air by arranging tablets in a single layer. This allows phosphine gas to evolve evenly and disperse freely throughout the silo.

Ensure trays remain level so tablets do not roll into one corner and become stacked. Tablets should always remain in a single layer for even gas release and to prevent residue powder smothering tablets below.

Photo 8: *Place phosphine in large enough trays that enable tablets to spread out in a single layer to avoid smothering as they liberate. (Source: Chris Warrick, Primary Business)*

Application with passive recirculation

Some silos are fitted with purpose-built chambers for applying phosphine from the bottom. This method of application carries a safety advantage as the operator doesn't have to leave the ground to apply the phosphine.

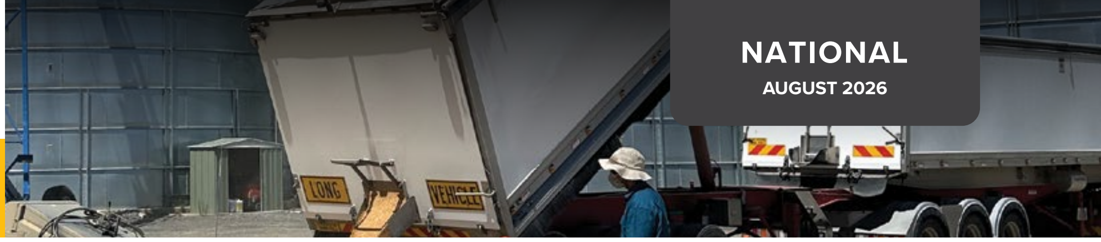
However, ensuring top lids or vent openings on silos are in sound condition and correctly sealed before fumigation will usually require a climb to the top.

Bottom-application chambers must have a passive or powered air recirculation system to carry the phosphine gas out of the confined space as it evolves. Without air movement, phosphine can reach explosive levels if it's left to evolve in a confined space.

Photo 9: *Some silos are built with a chamber and passive (thermo-siphon) or powered recirculation system for applying phosphine from the bottom. (Source: Ben White, Kondinin Group)*

VIDEOS

Fumigation recirculation



VIDEOS

[Explosion panel required in fumigation recirculation box]

VIDEOS

[Phosphine exposure in large grain storages with or without recirculation]

Application with powered recirculation

Silos larger than 150 t benefit from a gas-tight, powered recirculation system to distribute phosphine evenly throughout the grain bulk and achieve lethal gas concentrations more quickly. Trials have shown that, without powered recirculation, phosphine moves through grain at only about 6 m per day, regardless of direction.

For silos larger than 300 t without powered recirculation, the phosphine product label specifies an extended exposure period of 20 days, referred to as a surface-only application (Table 1). Powered recirculation distributes phosphine more rapidly throughout the silo, allowing the standard fumigation period of 7-10 days, depending on grain temperature, to be achieved.

Key components of a powered recirculation system include:

- *Gas-tight construction* – the recirculation chamber, ducting and pipework must not compromise the gas-tight integrity of the silo.
- Adequately sized recirculation chamber – large enough to accommodate phosphine tablets, bag chains or blankets without stacking, folding or restricting gas liberation.
- *Small recirculation fan* – gently circulates air from the headspace, through the phosphine chamber and into the base of the silo. High-capacity fans are unnecessary and may circulate phosphine residue dust from spent tablets.
- *Explosion-relief panel* – fitted to the recirculation chamber as a safety precaution. If the fan stops while phosphine is still being liberated, gas concentrations within the chamber could reach combustible levels.

Photo 10: *Powered recirculation improves gas distribution through a gas-tight sealable silo enabling 7-10 day exposure rather than 20-day exposure when fumigating silos greater than 300 t capacity. (Source: Chris Warrick, Primary Business)*

An alternative to a dedicated powered recirculation chamber is to install a small recirculation fan in the plumbing connecting the silo headspace to the aeration ducting at the base of the silo. Phosphine can then be placed directly in the headspace and/or the aeration ducting at the base, allowing the fan to circulate the gas throughout the grain bulk (see Photo 11).

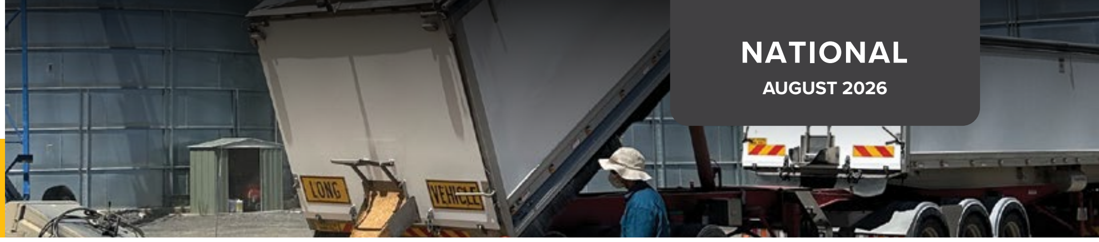


Photo 11: *Recirculation can be achieved by placing phosphine in the silo and plumbing a small fan from the silo headspace to the aeration duct. (Source: Chris Warrick, Primary Business)*

This approach offers two main advantages. Firstly, it eliminates the risk of an explosion within a dedicated phosphine chamber if the fan stops during gas liberation, as the phosphine continues to liberate safely within the silo. Secondly, the lower cost of the system makes it practical to install multiple recirculation fans, allowing several silos to be fumigated simultaneously.

6.1.6 Fumigation period

A gas-tight, sealed silo must remain sealed for the full 7-10 days to achieve a successful fumigation using phosphine.

In a gas-tight, sealed silo smaller than 300 t capacity, the required fumigation period is seven days if the grain temperature is above 25°C or 10 days if the grain temperature is between 15-25°C. If the grain temperature is below 15°C, insect pests will not be active and phosphine is not reliably effective.

In gas-tight, sealed silos larger than 300 t capacity that don't have powered recirculation, the exposure period is extended to 20 days regardless of grain temperature. If the silo has powered recirculation, the 7-10-day exposure depending on grain temperature applies (see Table 1).

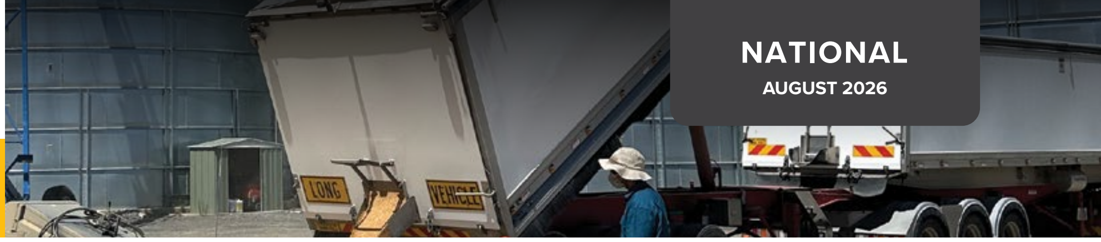
6.1.7 Ventilation period

Following fumigation, ventilate the silo to allow phosphine gas to disperse safely into the atmosphere before handling or delivering grain.

When a silo is first opened after a successful fumigation, phosphine concentrations can be extremely hazardous. The same PPE required when applying phosphine must also be worn when opening the silo and removing spent tablets, bag chains or blankets. Open the silo at least 30 minutes before removing the phosphine residue.

VIDEOS

Venting phosphine after fumigating grain



MORE INFORMATION

[The current guide for phosphine fumigation](#)

This allows phosphine concentrations to decrease, reducing operator exposure and the concentration of gas the respirator is required to filter.

Whenever possible, work with your side to the wind to minimise exposure to phosphine gas. Wearing a personal phosphine monitor provides an additional level of protection by continuously monitoring gas concentrations in the breathing zone.

After removing phosphine residue, silos without aeration fans should be left open to vent naturally for a minimum of five days. Silos fitted with aeration fans should be vented with the fans operating for at least one day (Table 1). Larger flat-bottom silos, cool grain or extended fumigations may require longer venting periods as phosphine continues to desorb from the grain. Always follow product label directions, comply with current Workplace Exposure Limits, and ensure grain meets the receival requirements of the delivery site to protect worker safety and avoid load rejections.

SAFETY TIP

The safest way to confirm that grain has been adequately ventilated is to use a low-range phosphine monitor. Test the grain several hours after the aeration fans have been switched off and immediately before out-loading or delivery. Sampling with a grain spear allows air within the grain bulk to be tested for phosphine released during desorption.

For the latest research results and guidelines on venting to comply with proposed changes by Safe Work Australia, see the link opposite – The current guide for phosphine fumigation.

Table 1: Phosphine fumigation guide

Type of Gas-tight Sealable Storage	Cone Bottom Silo	Cone or Flat-bottom Silo (No Powered Recirculation)	Cone or Flat-bottom Silo (with Powered Recirculation)	Well-sealed Bunker #	Well-sealed Grain Bag #
Capacity	Less than 300 t	More than 300 t	More than 300 t	More than 1000 t	200–300 t
Dosage if using tablets (per tonne of wheat capacity)	2 tablets /t	2 tablets /t	2 tablets /t	na	2 tablets /t
Dosage if using bag-chains or blankets (per tonne of wheat capacity)	1 x 340 g chain per 60 t *or* 1 x 680 g chain per 120 t	1 x 340 g chain per 60 t *or* 1 x 680 g chain per 120 t *or* 1 x 1.7 kg blanket per 300 t	1 x 340 g chain per 60 t *or* 1 x 680 g chain per 120 t *or* 1 x 1.7 kg blanket per 300 t	1 x 340 g chain per 150 t *or* 1 x 680 g chain per 300 t *or* 1 x 1.7 kg blanket per 750 t ##	na
Phosphine exposure (days) **Grain 15-25°C** **Grain > 25°C**	 10 7	 20 20	 10 7	 20 20	 10 10
Minimum ventilation (days) **No aeration fan** **Aeration fan**	 5* 1+*	 5* 1+*	 5* 1+*	2-5 days with flowthrough draft (wind)	 35** 2+**
Withholding Period (days)	2	2	2	2	2
Total fumigation process (days)	10 to 17	23 to 27	10 to 17	24 to 27	14 to 47

This table is a guide only – always refer to the manufacturer label directions.

High-range phosphine meters should be used in storages that cannot be pressure tested, to monitor concentration over time.

This 'half-rate' application is unlikely to provide reliable control. A fumigation contractor licensed to use cylinder phosphine is an alternative option.

* Label stipulated requirement, but experience suggests longer periods may be required pending clearance target levels.

** Guide only based on research conducted, not label specified.

Source: Kondinin Group

6.1.8 Withholding period

The label states that grain treated with phosphine should not be used for human consumption or for stock food for a minimum of two days after the ventilation period has finished.

Photo 12: *Signing storages under fumigation helps keep track of the process and warns others to keep away. (Source: Ben White, Kondinin Group)*

6.2 Other fumigants and controlled atmospheres

Although 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 is currently more expensive than using phosphine, but it is good practice to rotate chemistry for a resistance break.

Carbon dioxide (CO_2) and nitrogen (N) carry the advantage of being non-chemical control alternatives.

Both CO_2 and nitrogen are sometimes referred to as controlled atmosphere (CA) treatments because they change the balance of natural atmospheric gases to produce a toxic atmosphere.

6.2.1 Carbon dioxide

CO_2 is a non-flammable, colourless, odourless gas that is approximately 1.5 times heavier than air. Food-grade CO_2 comes as a liquid in pressurised cylinders and changes to a gas when released from the cylinder.

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 per cent for 15 days.

As a guide, the amount of CO_2 required to reach 35 per cent concentration for 15 days is one 30 kilogram (size G) cylinder per 15 t of storage capacity, plus one extra cylinder per storage, but measuring concentration is essential.

The basic process is to open the storage's top lid to let oxygen out as CO_2 is introduced at the base. Regulate the CO_2 gas into the bottom of the silo via a short, high pressure tube.

Each cylinder could take three hours to dispense if done slowly enough to prevent freezing, alternatively, a heated regulator can be used.

After the concentration at the top of the storage reaches 80 per cent, stop adding CO_2 and seal the top lid.

Even in a silo that meets the five-minute pressure half-life test, an initial CO_2 concentration of at least 80% is required to maintain an effective atmosphere above 35% for the full 15-day treatment period.

As the treatment progresses, the grain absorbs CO_2, causing the concentration within the storage to decline. The higher starting concentration ensures the atmosphere remains above the minimum effective level throughout the treatment period.

If CO_2 levels do decline during the fumigation, top-ups can be applied periodically over the 15 days if required. The key is to maintain the CO_2 concentration above 35 per cent for 15 consecutive days, which will require suitable electronic instruments or a gas tube detector kit for monitoring.

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. Disinfestation using a CO_2 controlled atmosphere is not recommended when temperatures are below 15°C.

6.2.2 Nitrogen

Nitrogen provides stored-grain insect control and grain quality preservation without the use of chemical fumigants. It is safe to use, environmentally acceptable and, once installed, has relatively low operating costs, with electricity being the primary ongoing expense.

Because nitrogen leaves no chemical residues, grain can be marketed immediately after treatment, unlike chemical fumigants that require venting and compliance with withholding periods.

Insect control with nitrogen uses Pressure Swing Adsorption (PSA) technology to produce high-purity nitrogen. The nitrogen-rich atmosphere is introduced into the base of the silo, displacing oxygen-rich air through the top of the storage. As oxygen concentrations fall, stored-grain insects are unable to survive.

PSA systems typically produce nitrogen at approximately 99.5% purity. Purging continues until the oxygen concentration within the silo is reduced to less than 2%. To achieve control of all insect life stages, including eggs, larvae, pupae and adults, oxygen concentrations below 2% must be maintained for 21 days when grain temperatures exceed 25°C. At grain temperatures below 25°C, the exposure period should be extended to 28 days.

The silo should be checked the day after purging, as oxygen can diffuse from the grain and increase oxygen concentrations within the headspace. Additional purging may be required to restore the target oxygen concentration.

Nitrogen storage also helps maintain the quality of canola and pulses by reducing oxidation. This slows seed deterioration, limits the development of free fatty acids and assists in maintaining grain colour during storage.

For further information on controlled-atmosphere storage using carbon dioxide or nitrogen, contact a commercial supplier of gas generation equipment or controlled-atmosphere storage systems.

6.2.3 Sulfuryl fluoride

Only licensed fumigators can apply sulfuryl fluoride (ProFume or Zythor). However, understanding how the fumigant works can help growers determine when it may be an appropriate option.

For grain intended for human consumption, sulfuryl fluoride is registered for use on cereal grains only (at the time of printing). For seed grain or grain intended for uses other than human consumption, it may also be used on other grain types where permitted by the product label. Always check with the intended grain buyer before using any fumigant or chemical treatment, as market requirements and residue tolerances may vary.

Sulfuryl fluoride provides effective control of most of the common stored-grain insect pests found in Australia, including rust-red flour beetle, lesser grain borer, saw-toothed grain beetle, flat grain beetle, rice weevil and Indian meal moth.

As with all fumigants, avoid rushed or shortened fumigations. Effective control of all insect life stages, including eggs, depends on maintaining the required gas concentration for the full label-specified exposure period in a gas-tight, sealed storage.

Before sulfuryl fluoride is applied, the licensed fumigator should use the Fumiguide software to calculate the correct dosage for the storage, grain temperature and target insect species.

For grain temperatures below 25°C, an exposure period of 7-10 days is generally required to achieve effective control of all insect life stages. Always follow the product label for the required dosage and exposure period.

Sulfuryl fluoride is approximately 3.7 times heavier than air. For best results, the gas should be introduced into the headspace of the silo. Research has shown that powered recirculation significantly improves gas distribution, helping achieve more uniform concentrations throughout the grain bulk.

The maximum application rate is 128 g/m^3. Following fumigation, the storage must be ventilated until sulfuryl fluoride concentrations are below 3 ppm before re-entry. Grain must not be consumed until the minimum 24-hour withholding period has elapsed.

For more information on sulfuryl fluoride, contact a commercial fumigator or TriCal Australia on 08 8347 3838 www.trical.com.au or for Zythor contact Ensystex 13 35 36 www.ensystex.com.au

6.2.4 VaporMate

VaporMate consists of 16.7% ethyl formate by weight, with the balance being carbon dioxide (CO_2). It is registered for use on cereal grains and oilseeds to control lesser grain borer, rust-red flour beetle, psocids, storage moths, saw-toothed grain beetle and flat grain beetle at all life stages, as well as rice weevil at the egg, larval and adult stages.

VaporMate is supplied as a liquefied gas under pressure and is applied in a gas-tight, sealed storage at a rate of 420 g/m^3 for 24 hours or 660 g/m^3 for three hours, depending on the treatment program. Always follow the product label.

Following fumigation, the storage must be ventilated until ethyl formate concentrations are below 100 ppm and CO_2 concentrations are below 5000 ppm. Once these clearance levels have been achieved, there is no withholding period.

Ethyl formate is readily absorbed by grain, making it more difficult to achieve the required gas concentration in the centre of large grain bulks. This can also extend the time required to adequately ventilate large storages following fumigation.

For more information on VaporMate contact BOC Gases Australia Ltd, on 13 12 62 or visit www.boc.com.au

6.3 Storage and treatment notes

6.3.1 Cereal grains delivered to customers

Buyers and bulk handlers are regularly changing their acceptance of grain treated with insecticides.

Before using a grain insecticide, always check with potential buyers and bulk handlers (depot) for market acceptability.

Identify storage pests before selecting a treatment. Always follow label instructions carefully.

6.3.2 Seed held on farm (cereals — wheat, barley, oats)

Seed that is dry, cool and free from weather damage will retain its viability for longer. Under well-managed storage conditions, germination typically declines by less than 5% over six months.

To maximise seed viability, maintain grain moisture content below 12% and use aeration cooling to keep grain temperatures at 20°C or below. Grain temperature has a major influence on both germination and seedling vigour.

Recent GRDC research conducted by Agriculture Victoria showed that high grain temperatures (30-35°C) combined with elevated grain moisture (14%) significantly reduced germination and seed vigour during long-term storage, regardless of variety.

Position small seed silos in a shaded spot, or paint them a reflective white colour, to help minimise heat gain and maintain cooler grain temperatures.

Harvesting seed grain at a cooler time of day will also provide the benefit of starting its storage period at a cooler temperature.

Treating seed with an appropriate grain protectant, together with aeration cooling and regular monitoring, will aid pest prevention while preserving seed quality. Always check the product label and seed buyer requirements before applying grain protectants to seed intended for sowing.

Photo 13: *To minimise mechanical seed damage, auger grain as few times as possible — harvester to truck, truck to farm storage, farm storage to truck — then deliver it. (Source: Chris Warrick, Primary Business)*

VIDEOS

GCTV18: Storing planting seed

MORE INFORMATION

Seeds need cool, dry conditions, no matter the variety

MORE INFORMATION

New research shows wheat falling number may improve after storage

VIDEOS

Falling number increase during storage

6.3.3 Falling number and wheat storage

GRDC-supported research by Agriculture Victoria has shown that storage conditions may influence wheat falling number after harvest. Preliminary trials found that, under specific storage conditions, wheat falling number increased by up to 50 seconds during storage and, in some cases, exceeded the 300-second threshold required for higher-value Australian wheat grades. No similar increase was observed in barley.

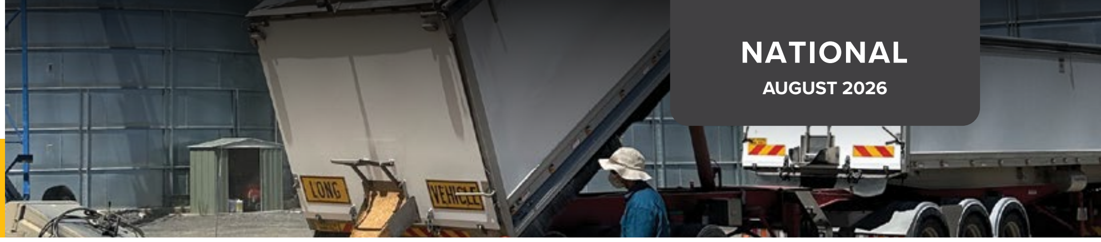
Only wheat with an initial falling number above 250 seconds showed the potential to improve during storage. The greatest increases were observed when wheat was stored at 25-30°C, with a grain moisture content of approximately 11%. Under these conditions, increases of 40-50 seconds typically occurred over a storage period of 4-6 months.

These findings remain preliminary and have yet to be validated across a wider range of wheat varieties, growing environments and commercial on-farm storage systems. Further research is required before recommendations can be made for routine management of falling number through storage.

Growers considering storing wheat to improve falling number should continue to prioritise safe grain storage practices.

In theory, growers may be able to operate aeration cooling normally during the initial cooling phase, then temporarily reduce fan operation once grain temperatures have reached approximately 25-30°C to delay further cooling while monitoring changes in falling number. If the desired falling number is achieved, normal aeration cooling should resume to reduce the risk of spoilage from mould and stored-grain insects.

Photo 14: *Preliminary findings indicate wheat with an initial falling number above 250 seconds showed the potential to improve during storage. (Source: Ben White, Kondinin Group)*



VIDEOS

GRDC Stored grain: Oilseeds and pulse storage

MORE INFORMATION

GRDC Grain Storage Fact Sheet: Storing Oilseeds

GRDC Grain Storage Fact Sheet: Storing Pulses

Best Management Practices for Storage of Pulses

VIDEOS

Storing pulses

6.3.4 Pulses and oilseeds

Insect control options are more limited for stored pulses and oilseeds than for cereal grains. Grain protectants are generally not registered for use on these commodities, leaving phosphine fumigation and controlled atmospheres, such as carbon dioxide or nitrogen, as the primary treatment options.

The effectiveness of phosphine fumigation in oilseeds can be reduced because phosphine is readily absorbed by the grain during treatment, making it more difficult to achieve and maintain the required gas concentration.

The best defence against insect infestations is an integrated approach combining meticulous grain hygiene, aeration cooling and regular monitoring.

Small-seeded grains, such as canola, create higher back pressure through the grain bulk and generally require higher-capacity aeration fans to achieve the recommended airflow rates. Always store pulses and oilseeds at their recommended moisture content to maximise grain quality and minimise the risk of mould, heating and insect activity.

Photo 15: *Aeration cooling is essential for storing oilseeds and may require higher-capacity fans to achieve airflow rates of 2-3 L/s/t in small-seeded crops such as canola. (Source: Chris Warrick, Primary Business)*

MORE INFORMATION

[CBH Guide: High moisture harvest and grain storage]

Managing high-moisture grain

Grain at typical harvest temperatures of 25-30°C and moisture content greater than 13-14 per cent provides ideal conditions for mould and insect growth. There are a number of ways to deal with high-moisture grain — the key is to act quickly and effectively.

7.1 Aeration drying

Aeration drying requires a purpose-designed system with substantially higher airflow rates than those used for aeration cooling. It is a much slower process than heated grain drying but can effectively reduce grain moisture under suitable climatic conditions.

In some situations, aeration cooling fans may reduce grain moisture slightly. However, these systems are not designed to reliably dry grain to a safe storage moisture content. Any apparent drying is often the result of moisture redistribution within the grain bulk rather than the removal of moisture from the storage.

Effective aeration drying requires airflow rates of approximately 15-25 L/s/t to push a drying front through the grain bulk (Figure 1). By comparison, aeration cooling systems typically operate at 2-4 L/s/t and are designed to cool grain rather than dry it.

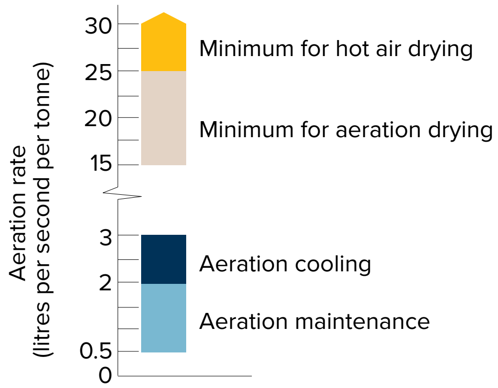


Figure 1: *Aeration rates for grain drying and cooling.*

Source: Kondinin Group

7.1.1 Managing moisture quickly

A Queensland Department of Agriculture and Fisheries (DAF) trial demonstrated how quickly over-moist grain can deteriorate when placed in an unaerated storage.

Wheat at 16.5% moisture content and 28°C was placed into a silo without aeration. Within hours, grain temperature had increased to 39°C, and within two days had reached 46°C—creating ideal conditions for mould growth, insect activity and grain deterioration.

Over-moist grain, generally above 13-14% moisture content, should be managed promptly to minimise the risk of heating, mould growth and insect infestation.

Figure 2 illustrates the likely outcomes under a range of grain moisture and storage conditions.

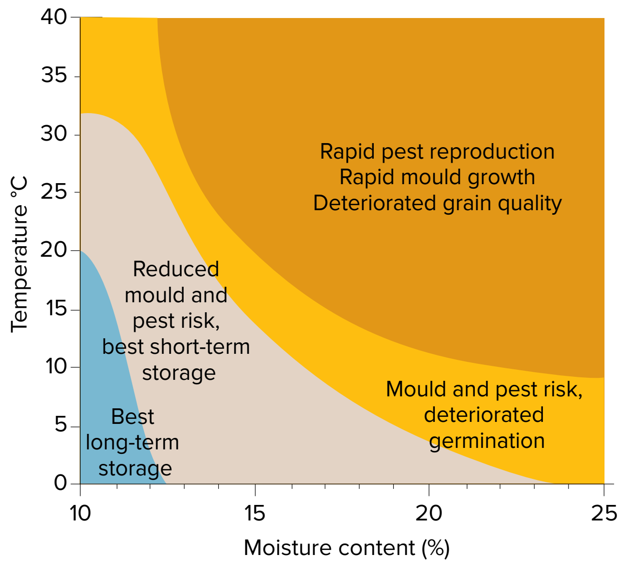


Figure 2: *Effects of temperature and moisture on stored grain*
Source: CSIRO Ecosystems Sciences

Moisture effects on seed germination

In addition to the visible degradation from mould and insect attack, storing over-moist grain risks germination loss.

CSIRO trials revealed that wheat stored at a typical harvest temperature of 30°C, without aeration cooling, has falling germination rates over time.

As moisture content exceeds 12 per cent, seed germination rate starts to fall more quickly (see Figure 3).

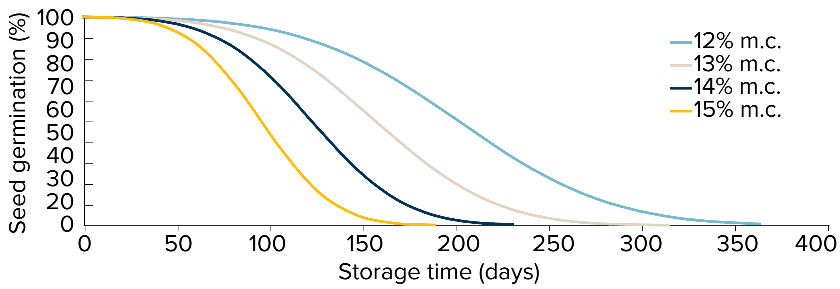


Figure 3: *Influence of moisture content (m.c.) on germination of wheat stored at 30°C.* Source: CSIRO

Recent GRDC-funded research by Agriculture Victoria has shown that aeration cooling improves grain quality by maintaining seed vigour, germination and grain colour during storage.

Aeration cooling also provides greater flexibility during wet harvests by allowing growers to manage grain with elevated moisture contents. While aeration cooling alone is not a drying system, it can temporarily hold slightly wetter grain before drying or facilitate the blending of wetter and drier grain to achieve a suitable storage and delivery moisture content.

More recent research and development has improved understanding of fan performance, static pressure and airflow distribution within silos. These findings should be considered when selecting new grain storages or retrofitting aeration systems to existing silos.

7.1.2 Options for high-moisture grain

Grain above the recommended safe storage moisture content (generally 12.5%) should be managed promptly using one of the following options:

- ✓ *Blend* – Mix higher-moisture grain with drier grain to achieve a safe overall moisture content, then cool the grain using aeration.
- ✓ *Aeration cooling* – Grain with a moderate moisture content (up to approximately 15%) can be held under aeration cooling for a short period until drying equipment becomes available.
- ✓ *Aeration drying* – A purpose-designed aeration drying system uses high airflow rates to move a drying front through the grain bulk, gradually removing moisture. Supplementary heating may be used where appropriate.
- ✓ *Continuous-flow drying* – Grain passes continuously through a dryer where large volumes of heated air remove moisture before the grain is transferred to storage.
- ✓ *Batch drying* – Grain is dried in batches, typically 10-20 t at a time, using a transportable dryer that forces heated air through the grain before it is returned to storage.

Photo 1: *If over-moist grain can't be dried immediately, hold it under aeration cooling until drying equipment is available. (Source: Phillip Burrill, DAF QLD)*

Blending

Blending involves mixing slightly over-moist grain with drier grain to achieve an overall moisture content below the recommended safe storage level of 12.5%.

For grain up to approximately 13.5% moisture content, blending can be a simple and cost-effective option, provided suitable handling and storage infrastructure is available.

Without aeration cooling, the grain must be blended thoroughly to achieve a uniform moisture content throughout the storage. Where aeration cooling is available, grain can be blended in layers, as the cooling front will help equalise temperature and moisture within the grain bulk (Figure 4).

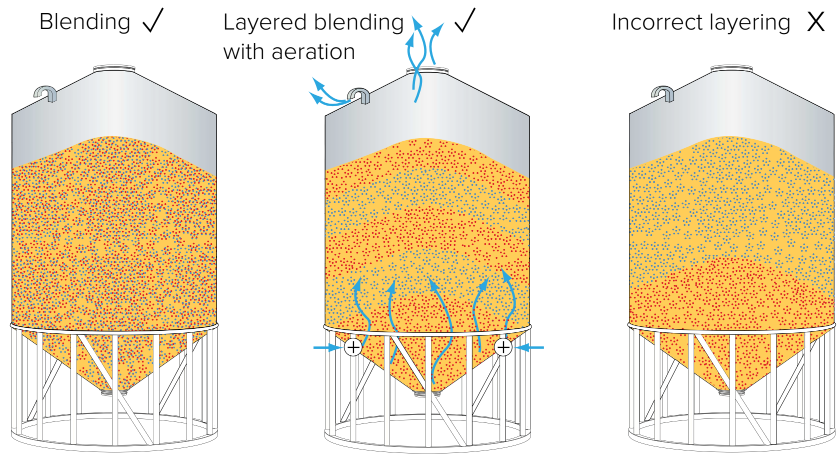


Figure 4: *Correct blending.*

Source: Kondinin Group

Assisted by aeration cooling, with time, moisture from the wet grain will migrate into the drier grain around it and the grain stack will end up being reasonably uniform in moisture content.

A blending example

Grain harvested during the middle of the afternoon might have a moisture content of 11 per cent and can be put aside for blending. The harvester can then work a little longer each day and harvest grain at 13.5 per cent moisture content.

The 11 per cent and 13.5 per cent moisture content grain can be blended at a ratio of 60:40 to produce an average moisture content of 12 per cent.

To allow a margin for error in blending it would be safer in this scenario to blend 70 per cent of the drier grain to 30 per cent of the wet grain.

7.1.3 Holding over-moist grain with aeration cooling

Over-moist grain often needs to be held temporarily until drying equipment becomes available or conditions allow drying to proceed.

As shown in Figure 2, grain harvested with both high moisture content and elevated temperature is at greatest risk of mould growth, insect activity and quality deterioration. In these situations, reducing grain temperature with aeration cooling can significantly slow deterioration and safely hold the grain until drying can be completed.

Aeration cooling systems delivering 3-4 L/s/t can effectively cool grain containing up to 14-15% moisture content for short-term storage. Under these conditions, grain can generally be held safely for up to one month, provided the aeration system operates continuously and the grain is monitored regularly.

Fans should operate continuously during this holding period, only being switched off if ambient relative humidity remains above 85% for more than about 12 hours, to avoid re-wetting grain around the aeration ducts.

If humid conditions persist for an extended period, operate the fans periodically to remove heat from the grain. Preventing grain heating is generally more important than the small amount of moisture that may be added during these short operating periods.

Forcing air through over-moist grain creates an evaporative cooling effect, allowing grain temperature to fall rapidly. Because of this, there is generally no need to wait for cool ambient conditions before commencing aeration.

VIDEOS

Holding over moisture grain with aeration cooling

VIDEOS

GCTV5: Aeration drying – getting it right

Regular monitoring is essential. If the aeration system fails, or airflow is not distributed evenly through the grain bulk, hot spots can develop quickly, increasing the risk of mould growth, insect infestation and grain quality loss.

7.1.4 Aeration drying

Aeration drying uses high airflow rates to gradually remove moisture from grain. It is typically carried out in a purpose-built drying silo or in a silo fitted with high-capacity aeration fans and partially filled with grain to achieve the required airflow.

Aeration drying is a relatively slow process and relies on warm, dry ambient conditions. Successful drying depends on both correct system design and careful fan management.

Poorly designed systems or incorrect fan operation can reduce grain quality or result in uneven drying.

Successful aeration drying requires four key components:

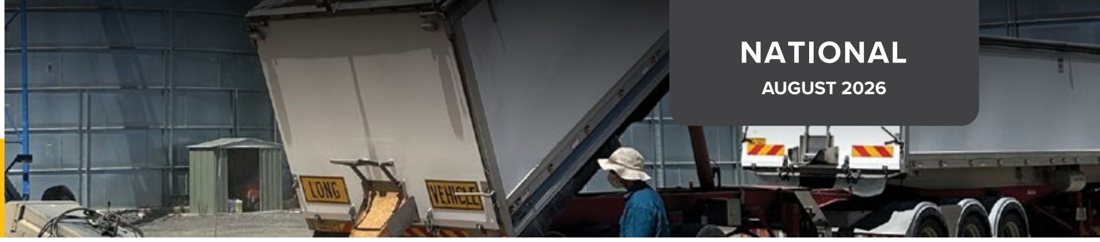
- Airflow rates of 15-25 L/s/t.
- Well-designed aeration ducting to ensure even airflow throughout the grain bulk.
- Adequate roof exhaust vents to allow moist air to escape from the silo.
- Warm, dry ambient conditions to maximise the drying potential of the incoming air.

Photo 2: *A purpose-built silo for aeration drying has a large fan capable of more than 15 L/s/t with ducting right around the silo cone. (Source: Alex Conway)*

High airflow for drying

Unlike aeration cooling, aeration drying requires airflow rates of 15-25 L/s/t to move the drying front quickly through the entire grain bulk and carry moisture out of the storage.

As air passes through the grain, it absorbs moisture and forms a drying front. This moisture-laden air must be forced completely through the grain and exhausted from the top of the silo before fresh, drier air can continue the drying process. If airflow is insufficient, the drying front moves too slowly and may fail to reach the top of the grain bulk.



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Grain Aeration Design and Performance Guide 2024

If weather conditions become unsuitable for drying, or fans are switched off for extended periods, the drying front can stall. Grain above the drying front remains warm and moist, creating ideal conditions for mould growth and grain deterioration.

One way to increase the effective airflow rate is to only partially fill the storage. A shallower grain depth reduces back pressure on the aeration fan, increasing airflow through the grain. For example, a 100 t silo fitted with fans delivering 4 L/s/t when full will achieve an effective airflow rate of approximately 20 L/s/t when holding only 20 t of grain, assuming airflow uniformity can still be achieved.

Providing the storage has adequate aeration ducting, a drying front will move through a shallow grain profile much more quickly than a deep one. Because air follows the path of least resistance, grain should be spread as evenly as possible to maintain a uniform grain depth across the storage.

Resistance to airflow

Although the physics of airflow is complex, understanding static pressure is essential when designing an effective aeration drying system.

Static pressure is the resistance to airflow created by everything downstream of the fan, including the aeration ducting, grain bulk and roof exhaust vents. As airflow increases, static pressure rises rapidly, reducing the amount of additional airflow that can be achieved. This is why simply fitting a larger fan will not proportionally increase airflow through the grain.

Aeration duct design has a major influence on static pressure. Large, well-designed perforated ducts distribute air more evenly and create less resistance than a single narrow outlet delivering the same airflow.

Grain type also influences static pressure. Small-seeded grains such as canola create much higher resistance than wheat because the smaller spaces between the seeds make it more difficult for air to pass through the grain bulk.

Grain depth is another major contributor to static pressure. As grain depth increases, the fan must force air through a greater volume of grain before it can escape from the top of the storage, increasing resistance and reducing airflow.
See Section 5.4.9 Airflow distribution within silos.

Ducting for drying

Air supplied by an aeration fan will always follow the path of least resistance through the grain, usually taking the shortest path from the aeration duct to the grain surface.

For effective moisture removal, airflow must be distributed as evenly as possible throughout the entire grain bulk. Areas receiving little or no airflow will not dry and remain at risk of heating, mould growth and grain deterioration. These areas are commonly referred to as hot spots.

Well-designed aeration ducting is essential to minimise hot spots by distributing airflow evenly throughout the storage. In flat-bottom silos, a full-floor aeration plenum or multiple aeration trenches covered with perforated flooring provide the most uniform airflow, provided fan capacity is sufficient for the volume of grain being dried.

Where fan capacity is limited, partially filling a flat-bottom silo is often more effective than attempting to dry a full cone-bottom silo with inadequate aeration ducting.

Avoid ducting systems that split airflow from a single fan between multiple silos. Although the fan's rated capacity may appear sufficient, the actual airflow delivered to each silo will depend on the static pressure of each system. Unless the silos are identical in size, have the same ducting layout, contain the same grain type and are filled to the same depth, airflow will be uneven. The silo with the higher static pressure will receive less airflow, increasing the risk of uneven drying and hot spots.

Ducting — the trap

Increasing the amount of aeration ducting generally improves airflow distribution through the grain. However, it can also make the storage more difficult to clean.

When installing aeration ducting, or purchasing a storage fitted with ducting or a full-floor aeration plenum, consider how easily the system can be accessed and cleaned.

Aeration ducting commonly traps dust, grain and other residues as the storage is emptied, providing an ideal harbour for stored-grain insect pests. Unless these residues are removed during routine maintenance, insects can survive between seasons and infest the next parcel of grain placed into storage.

Exhaust vents

An often-overlooked component of aeration drying is providing adequate exhaust ventilation. Air forced into the base of the silo must be able to escape freely through the roof. For example, delivering 20 L/s/t through 60 t of grain requires an airflow of 1200 L/s into the storage, meaning 1200 L/s must also be able to exit without restriction. Inadequate roof venting increases static pressure and reduces airflow through the grain.

Exhaust ventilation must also allow moisture removed from the grain to escape from the storage. As shown in Table 1, removing 1% moisture content from 1 t of grain releases approximately 10 L of water. Unless this moisture is effectively exhausted, drying efficiency is reduced and condensation may develop within the storage.

Table 1: Litres of water removed during grain drying

	Percentage of moisture content reduction				
Tonnes of grain	**1%**	**2%**	**3%**	**4%**	**5%**
1	10	20	30	40	50
50	500	1,000	1,500	2,000	2,500
100	1,000	2,000	3,000	4,000	5,000

Source: Kondinin Group

Using the previous example, removing 1% moisture content from 100 t of grain requires approximately 1000 L of water to be exhausted from the silo. Without adequate roof ventilation, this moisture can condense on the underside of the roof and drip back onto the grain surface, increasing the risk of mould and grain deterioration.

Roof vents should be weatherproof so they can remain open during rainfall. Although aeration drying fans are normally switched off during rain, the silo still requires passive ventilation to prevent condensation forming in the headspace.

Where a silo is also used for fumigation, roof vents must be capable of being sealed to maintain a gas-tight storage. New sealable silos should comply with AS2628–2010 by achieving a five-minute pressure half-life test. Well-maintained older silos achieving a three-minute pressure half-life have been shown to provide effective fumigation, although this does not meet the current Australian Standard for new installations.

Photo 3: *Because aeration drying requires high airflow, extra ventilation is needed to allow air and moisture to escape the silo unrestricted. (Source: Chris Newman, DPIRD)*

Weather conditions for drying

Successful aeration drying depends on selecting air that is capable of absorbing moisture from the grain. The most important factor determining this is the relative humidity of the incoming air.

Although warm air increases the rate of drying, relative humidity has the greatest influence on whether drying occurs at all.

Each grain type has an equilibrium moisture content (EMC), where the grain is in balance with the surrounding air. At this point, there is no net movement of moisture between the grain and the air.

For drying to occur, the relative humidity of the incoming air must be lower than the grain's equilibrium relative humidity. For example, the equilibrium tables on the following pages show that wheat at 25°C and 14% moisture content has an equilibrium relative humidity of approximately 70%. In this situation, the aeration drying fans should only operate when the ambient relative humidity is below 70%, allowing moisture to move from the grain into the air.

Refer to the equilibrium moisture content tables on the following pages (or the QR code opposite) for equilibrium values for different grain types.

MORE INFORMATION

Equilibrium tables — grain moisture content to air relative humidity

7.1.5 Fan operation for drying

Unlike aeration cooling, aeration drying requires both higher airflow rates and a different fan control strategy. The objective is not simply to cool the grain, but to remove moisture by moving a drying front through the grain bulk.

When over-moist grain is first placed into storage, it is critical to move large volumes of air through the grain for most of each day. This rapidly removes surface moisture, promotes movement of the drying front and helps prevent the grain from self-heating during the initial storage period.

Phase one of drying

Aeration drying fans should be started as soon as the grain covers the aeration ducting and operated continuously until the first drying front has moved through the entire grain profile. This typically takes 5-7 days, depending on airflow rate, duct design, grain moisture content, ambient conditions and the depth of grain in the storage.

During this initial drying phase, fans should only be switched off if the ambient relative humidity remains above 85% for more than a few hours. A short-lived increase in relative humidity, such as during a passing storm, is unlikely to have a significant effect. However, prolonged operation above 85% relative humidity can re-wet the grain because the surrounding air is wetter than the grain's equilibrium moisture content.

An aeration controller with a drying mode can automate this process by switching the fans off when ambient relative humidity reaches 80-85%. However, the accuracy of relative humidity sensors varies between controllers. Some sensors become less accurate at higher relative humidities, so the controller may need to be set to around 80% to ensure fans stop before ambient conditions exceed 85% and begin re-wetting the grain.

The risk of wet weather

Because aeration drying relies entirely on ambient conditions, prolonged periods of high relative humidity present the greatest risk. If ambient relative humidity remains above 85% for an extended period, drying will stall and over-moist grain can quickly deteriorate.

If over-moist grain is being held in storage while waiting for suitable drying conditions, operate the aeration fans for a short period each day to flush fresh air through the grain. Running the fans for a few hours is unlikely to significantly increase grain moisture content, but it will help remove heat and reduce the risk of self-heating and mould development.

During these periods, monitor grain temperature and moisture content daily. An increase in grain temperature is an early warning sign of self-heating, mould growth or insect activity and requires immediate investigation.

If drying conditions do not improve, or hot spots develop within the grain bulk, the safest option is to turn the grain. Removing and returning the grain to the storage mixes the grain, disperses hot spots and provides an opportunity to reassess grain condition before continuing storage or drying.

Phase two of drying

Once the initial drying front has moved through the grain and the air leaving the top of the storage feels cool and smells clean and fresh, fan operation can become more selective.

By regularly monitoring grain temperature and moisture content, and referring to the equilibrium moisture content (EMC) tables for the grain type, an appropriate relative humidity set point can be selected for the aeration controller.

As grain moisture content decreases, its equilibrium moisture content also changes. To continue drying, the relative humidity set point should be progressively lowered so the incoming air remains capable of removing moisture from the grain.

There are no fixed rules for operating an aeration drying system because drying performance depends on many interacting factors, including grain type, moisture content, airflow rate and prevailing weather conditions.

The key is to regularly monitor grain moisture content and only operate the fans when the incoming air has a lower equilibrium relative humidity than the grain. Under these conditions, moisture will continue to move from the grain into the air, allowing drying to progress.

Drying the whole storage

When monitoring grain during aeration drying, measure both grain moisture content and temperature at the top and bottom of the storage. In most cases, grain closest to the aeration ducting will dry more quickly than grain near the top of the stack.

During the second phase of drying, gradually lowering the relative humidity set point helps maintain adequate fan run time, allowing each drying front to move completely through the grain bulk. This minimises the moisture difference between the bottom and top of the storage.

As air moves upward through the grain, it absorbs moisture from the lower layers before continuing towards the top of the storage. As a result, the grain nearest the roof is always the last to dry.

Becoming too selective with fan operation too early can significantly reduce daily run times, preventing the drying front from reaching the top of the grain stack. This leaves the upper grain layers wetter for longer, increasing the risk of uneven drying and grain deterioration.

Table 2: Effect of increased inlet air temperature

	Starting conditions	Increasing inlet air temperature with supplementary heating			
		+4°C	+6°C	+8°C	+10°C
Air temperature (dry bulb)	25°C	29°C	31°C	33°C	35°C
Relative humidity (RH)	70%	56%	49%	44%	39%
Approximate equilibrium wheat moisture with starting RH of 70%	14.0%	11.8%	11.0%	10.2%	9.6%
Outcome starting with a higher relative humidity					
Relative humidity	90%	71%	64%	57%	51%
Approximate equilibrium wheat moisture with starting RH of 90%	>16%	14.1%	12.7%	11.7%	10.8%

Source: GRDC

Equilibrium table for sorghum

Sorghum Equilibrium moisture content — Grain Moisture (%)

Relative Humidity (%)	Temperature (°C) 0	5	10	15	20	25	30	35	40	45
90				18	18					
88		18	18				17	17		
86	18			17	17	17		16	16	
84			17			16	16			
82		17		16	16			15	15	
80	17		16				15			14
78		16			15	15			14	
76	16			15				14		
74			15				14			13
72		15				14			13	
70					14			13		
68	15			14			13			12
66			14			13			12	
64		14			13			12		11
62	14			13					11	
60			13				12	11		
58		13				12				
56					12		11			10
54	13			12		11			10	
52			12		11			10		
50		12					10			
48				11		10				
46	12		11		10					
44		11		10						
42	11		10							
40		10								
38	10									

Equilibrium table for wheat

Wheat Equilibrium moisture content — Grain Moisture (%)

Relative Humidity (%)	Temperature (°C) 0	5	10	15	20	25	30	35	40	45
90						16			15	
88					16			15		
86							15			
84				16						
82						15				14
80			16						14	
78					15			14		
76		16								
74				15			14			13
72	16								13	
70			15			14		13		
68		15			14					12
66				14			13			
64	15					13			12	
62			14							
60					13			12		11
58		14					12			
56				13		12			11	
54	14		13							
52					12			11		
50		13					11			
48				12		11				10
46									10	
44			12		11			10		
42	13						10			
40				11		10				9
38		12							9	
36			11		10			9		
34										
32				10			9			
30		11				9				
28	12		10							
26					9					
24										
22		10		9						
20	11		9							
18										
16		9								
14	10									
12										
10	9									

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