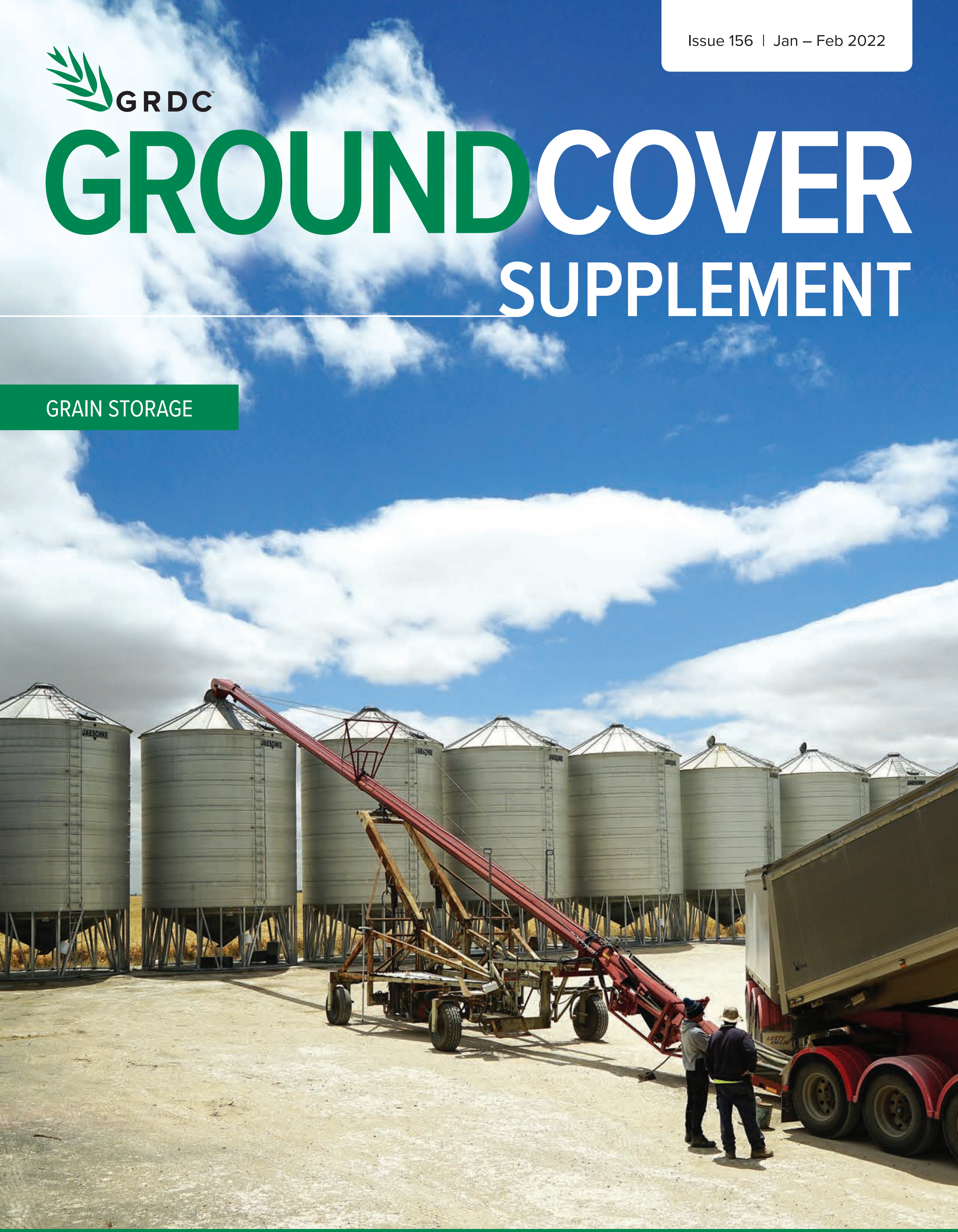
Issue 156 | Jan – Feb 2022

GRDC

# GROUNDCOVER SUPPLEMENT

GRAIN STORAGE



# TODAY'S GRAIN STORAGE INVESTMENTS SUPPORT TOMORROW'S WORLD

## The past 30 years have been a tumultuous period in grain storage infrastructure and technology

**By** Graeme Sandral and Leigh Nelson

■ The rise of centralised bulk handers capable of receiving multiple grain segregations, along with increased on-farm storage, has resulted in a plethora of niche marketing opportunities that have replaced the old original network of about 900 local silos around the country. Some, like the one at Rosebery, Victoria (pictured), now host an epic artwork attracting a line of tourists swapping caravan stories, rather than a line of grain trucks.

But silo closures are only part of the story. These changes have provided greater opportunities for growers to both target and time their marketing to achieve premium farmgate prices, or access niche markets and quality segregations.

The shift to on-farm storage has also been driven by the need to streamline logistics in response to improvements to harvest efficiency and capacity, and the need to reduce downtime and freight costs. Grain is also stored for future sowing or to support diversification through livestock or value-adding.

### INVESTING IN CHANGE

GRDC's investment has focused on enabling grain growers to design and actively manage reliable, fit-for-purpose and cost-effective on-farm grain storage and handling systems. Our goal is for grain growers to optimise profit from every tonne of grain by reducing costs and capturing greater value from the full range of market opportunities.

Our investments focus on grain storage practices, managing pests and limiting insecticide resistance, safety and protecting grain quality to ensure long-term profitability through access to high-quality markets.

Central to this is our investment in the 'Grain Storage Extension Project', which has supported growers to implement change during a period where the volume of grain stored on-farm has doubled. A dedicated extension team works closely with growers, researchers and industry to share information and help identify areas that need further research and extension.

A key aspect of on-farm storage is workplace safety. Climbing silos, using chemicals and operating augers and other moving parts all pose a risk. While advances in technology can overcome some of these issues, educating growers on safe practices and potential improvements is a top priority.

Through our investment in 'National Resistance Monitoring for Insect Pests of Stored Grain' we aim to maximise the efficacy of insect control and limit the further development of insecticide resistance to ensure we can meet market demands for insect-free grain.

With many growers choosing to hold grain on-farm for a year or more, we are also targeting investment to better understand the impact of storage conditions on grain quality and to better understand what is within our control.

Just as the investments growers make today in on-farm storage infrastructure will serve them for many years into the future, we are confident GRDC's current investments are not only of value to growers today but also will continue to deliver for many years to come. □

Photo: René Riegal, Unsplash

Grain storage and marketing changes have seen a greater centralisation of bulk handlers and a plethora of niche marketing opportunities replace the original network of approximately 900 local silos. Some smaller storage facilities, like the pictured silo at Rosebery, Victoria, now host epic artworks instead of grain.

**More information:** Graeme Sandral, 0409 226 235, graeme.sandral@grdc.com.au; Leigh Nelson, 0408 305 600, leigh.nelson@grdc.com.au

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

***GroundCover™* is brought to you by growers and the Australian Government through the publisher, Grains Research and Development Corporation (GRDC).**

**To subscribe to GroundCover™ email your full name and postal details to subscribers@grdc.com.au or write to: GroundCover™, PO Box 5367, KINGSTON ACT 2604**

**GRDC:** 02 6166 4500, fax 02 6166 4599

**WRITE TO:** The Editor – *GroundCover*™, PO Box 5367, Kingston ACT 2604

**EXECUTIVE EDITOR:** Ms Maureen Cribb, manager, integrated publications, GRDC, 02 6166 4500

**CONTENT CREATION AND PRODUCTION:** Coretext Pty Ltd, www.coretext.com.au

***GROUNDCOVER™ SUPPLEMENT*** edited by Katherine Hollaway

**COVER IMAGE:** Increasing their on-farm grain storage capacity allows growers to optimise profitability and streamline logistics. **PHOTO:** Chris Warrick

**PRINTING:** IVE Group

**CIRCULATION:** Ms Maureen Cribb, 02 6166 4500

To view stories from past editions of *GroundCover*™ go to: groundcover.grdc.com.au

**ISSN** 1039-6217 Registered by Australia Post Publication No. NAD 3994

**PLANT BREEDER'S RIGHTS:** PBR denotes that the variety is protected by Plant Breeder's Rights (ᴾᴮᴿ).

**DISCLAIMER:** This publication has been prepared in good faith by Grains Research and Development Corporation (GRDC) on the basis of the information available to us at the date of publication, without any independent verification. Neither GRDC, its editors nor any contributor to this publication represent that the contents of this publication are accurate or complete; nor do we accept any responsibility for any errors or omissions in the contents, however they may arise. Readers who act on information from *GroundCover*™ do so at their own risk. GRDC and contributors to *GroundCover*™ may identify products by proprietary or trade names to help readers identify particular types of products. We do not endorse or recommend the products of any manufacturer referred to. Other products may perform as well as or better than those specifically referred to.

**CAUTION: research on unregistered agricultural chemical use**

Any research with **unregistered agricultural chemicals** or of unregistered products reported in *GroundCover*™ does not constitute a recommendation for that particular use by the authors or the authors' organisation/s.

All **agricultural chemical** applications must accord with the currently registered label for that particular pesticide, crop, pest and region.

**COPYRIGHT:** © All material published in *GroundCover*™ is copyright protected and may not be reproduced in any form without written permission from GRDC.

# Meet the dedicated team improving on-farm grain storage

**GRDC's grain storage extension team is on the ground to help growers get more from on-farm storage**

**KEY MESSAGE**

GRDC's grain storage extension team has supported growers through a doubling of on-farm grain storage capacity over the past 12 years.

■ Not every grain grower is able to buy new storage, but every grower should have access to information to help select and effectively utilise the most appropriate storage options for their business.

Over the past 12 years, GRDC has invested in the 'Grain Storage Extension Project' to help the industry to adjust during a period when on-farm storage capacity has doubled. The team's role is to extend research findings and provide a feedback loop for grower questions and information gaps requiring research. The extension team works closely with researchers, growers and industry.

Over the past three years alone, the team has delivered 244 workshops to 6300 growers, advisers and industry personnel.

In addition to the workshops, extension activities have included publishing an 86-page *GrowNotes*™ *Grain Storage* manual, maintaining the dedicated storedgrain.com.au information hub and providing direct telephone support via 1800 WEEVIL. The team members also extend messaging through multimedia and social media channels, support manufacturers and commercial operators and are actively involved in industry organisations and groups.

## MEET THE TEAM

Bringing 19 years' experience in his current role, Philip Burrill is based in Warwick, Queensland, and has a lifetime of knowledge in grain production and storage. Recognised by GRDC's northern Seed of Light Award in 2018, Philip's dedication to helping growers improve their on-farm grain storage is second to none.

Philip, who works at the Queensland Department of Agriculture and Fisheries (DAF), has regular interaction with DAF's post-harvest research team based in Brisbane, which is supported by GRDC investment. This promotes a two-way flow of research results and feedback from growers on required research.

Ben White has built a career in researching and sharing information with growers to foster improvements to operations and profitability. Based in Perth, Western Australia, Ben was also recognised with GRDC's Seed of Light Award (western region) in 2021. With a rural background and as a qualified engineer, Ben brings strengths to the team in managing various storage facilities, aeration systems and exploring new technology.

Based in Horsham, Victoria, Chris Warrick leads the national collaborative team and brings both practical and business experience with a degree in farm business management. After years of training from Philip and the late Peter Botta, Chris not only delivers information to GRDC's southern region growers, but also coordinates the national suite of resources and project outcomes.

## NOW AND INTO THE FUTURE

Survey results indicate that the project is driving change in key areas of on-farm storage best practice. Importantly, these include an increase in the proportion of on-farm storage capacity that is gas-tight-sealable, which has surpassed 50 per cent, to enable effective and reliable fumigation of grain (Figure 1).

While the need for gas-tight-sealable storage is not yet accepted by every grower and manufacturer, the survey results show an encouraging and steady increase – 76 per cent of growers now have at least some sealable storage on-farm, up from 56 per cent a decade ago.

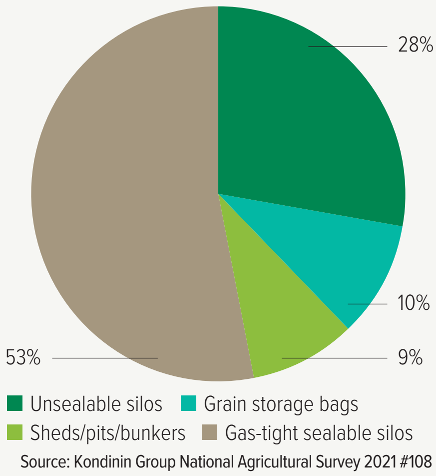
Recently identified information gaps are being addressed through GRDC investment in development activities. These activities, specifically aimed at answering questions and identifying research gaps, are an opportunity to field-test theories, new technology and validate lab research.

In 2021, Toowoomba engineer Alex Conway joined the team on a part-time basis as part of a capacity-building drive and has been learning all he can, working alongside Philip. The team is also looking to appoint another person in the near future. □

**GRDC Code PRB2011-001SAX**

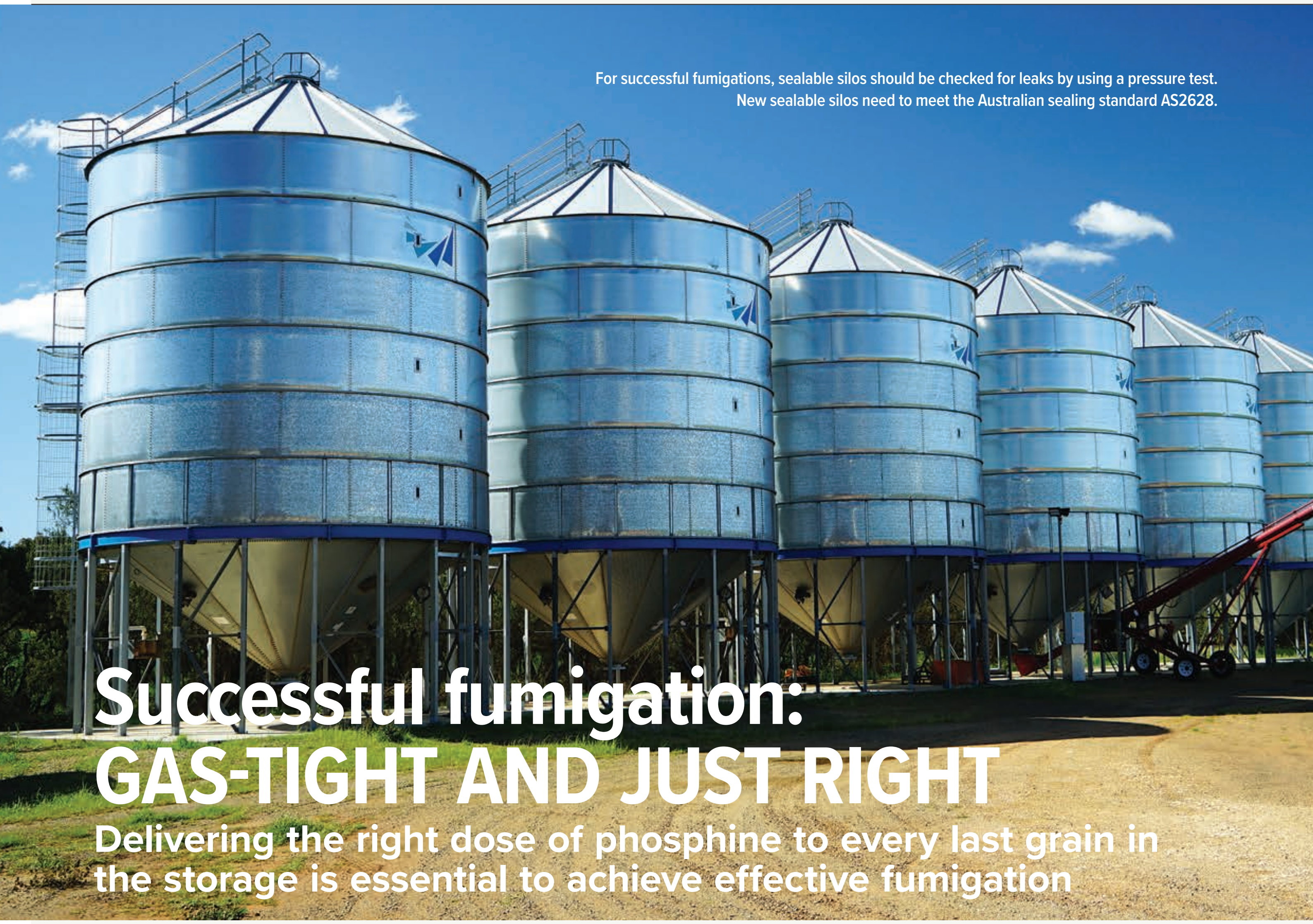
**More information:** 1800 WEEVIL, info@storedgrain.com.au, storedgrain.com.au, grdc.com.au/grain-storage-grownotes

**Figure 1: On-farm storage capacity by type.**




Source: Kondinin Group National Agricultural Survey 2021 #108

GRDC's grain storage extension team (left to right): Philip Burrill, Ben White, Chris Warrick and Alex Conway, who have supported growers during a period when on-farm storage capacity has doubled.



For successful fumigations, sealable silos should be checked for leaks by using a pressure test. New sealable silos need to meet the Australian sealing standard AS2628.

Photo: Philip Burrill

# Successful fumigation: GAS-TIGHT AND JUST RIGHT

## Delivering the right dose of phosphine to every last grain in the storage is essential to achieve effective fumigation

**By** Philip Burrill, Dr Manoj Nayak, Dr Greg Daglish and Dr Raj Jagadeesan

### KEY POINTS

- Successful pest control in storages depends on combining regular grain monitoring, good hygiene, aeration cooling and correct fumigation practices
- Fumigation results rely on a gas-tight sealable storage to achieve the required gas concentrations and exposure times (C x T) to kill all insect pest life stages
- In larger silos (150 to 2000 tonnes) recirculating gases using a small fan during the fumigation ensures rapid, uniform distribution of phosphine gas

■ To prevent the development of resistance in insect pests, it is essential to make sure that phosphine works properly first time, every time.

As the main fumigation chemical that growers use to control grain storage insect pests, phosphine plays an important role in combination with grain monitoring, good hygiene, aeration cooling and, when appropriate, grain protectants. But careful attention needs to be paid to the finer details to achieve effective fumigations and successful pest control.

### WHY GAS-TIGHT?

It is essential that fumigation fully controls each life cycle stage of storage pests: eggs, larvae, pupae and adults. This requires a given minimum gas concentration (C), for a specified length of time (T). If this fumigation exposure (C x T) requirement is not achieved throughout the storage space, it is likely the various insect life stages, such as eggs and pupae, will survive in the grain.

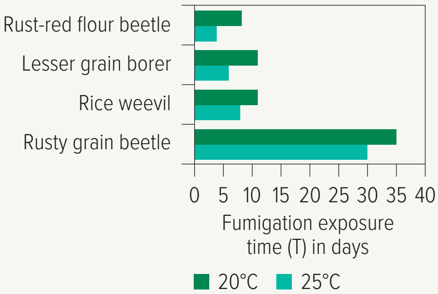
The phosphine fumigation C x T dose required to control all life stages of virtually all storage pest species is a minimum of 360 parts per million (ppm) phosphine gas concentration for 10 days at a grain temperature of 25°C (Figure 1).

Silos that are not sealed, gas-tight, during the fumigation period cannot achieve this minimum dose. When buying a new silo, select one that meets the Australian sealing standard AS2628. Also, conduct a pressure test on existing sealable silos to identify any leaks prior to a fumigation.

Repeating poor-quality grain fumigations in leaky, non-gas-tight silos not only gives poor results, but it also selects for insects with phosphine resistance genes. This eventually causes increased resistance in pest populations.

Storage insect pest populations in Australia include insects with both weak and strong resistance. About 10 to 11 per cent of storage pest populations collected from eastern Australian farms

**Figure 1: Phosphine fumigation exposure times at 360ppm required to control the full life cycle of strongly phosphine-resistant insect populations at 20°C and 25°C grain temperatures.**




Source: Raj Jagadeesan

Photo: Philip Burrill

Using a small fan (0.37 kilowatt pictured) during fumigation to recirculate phosphine gave rapid uniform gas distribution in 1423 tonnes of wheat, resulting in 750ppm in all parts of the silo in just over one day.

## REPEATING POOR-QUALITY GRAIN FUMIGATIONS IN LEAKY, NON-GAS-TIGHT SILOS NOT ONLY GIVES POOR RESULTS, BUT IT ALSO SELECTS FOR INSECTS WITH PHOSPHINE RESISTANCE GENES.

for resistance testing are strongly resistant. Except for rusty grain beetle, strongly resistant insects can still be controlled with correct fumigation practices using the recommended phosphine label rate (C x T) in a sealable silo.

Strongly phosphine-resistant rusty grain beetle (*Cryptolestes ferrugineus*), one of the flat grain beetles, can be controlled by fumigating with an alternative gas such as sulfuryl fluoride (ProFume®, Zythor®).

### FUMIGATION ADJUSTMENTS

Aeration cooling protects grain in storage but also slows insect activity, which changes fumigation requirements.

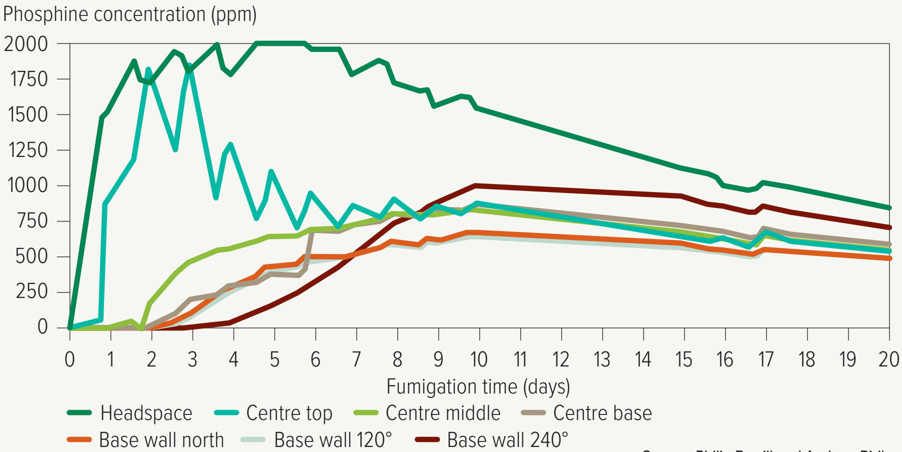
Fumigation time increases by a few days as grain temperatures drop from 25°C to 20°C (Figure 1). As insect metabolism (internal activity) is slowed for each of the insect's life stages, including eggs, additional fumigation time is required to ensure toxins can build to lethal levels in the insect's cells to kill each life stage.

Phosphine labels specify a seven-day fumigation exposure time for grain temperatures above 25°C and 10 days for grain temperature between 15°C and 25°C.

During fumigation, phosphine gas is typically liberated over a period of four to six days from tablets or blankets.

Phosphine gas moves slowly through grain – about six metres every 24 hours through cereal grain – meaning it can take two to five days to reach all areas within a medium to large silo (approximately 150 to 2000 tonnes, Figure 2). In large-silo fumigations, this may result in some grain, at the furthest distance from tablets or blankets, seeing a much-reduced phosphine gas exposure time (T). This is likely to result in poor control of the full life cycle, especially eggs and pupae.

**Figure 2: Phosphine gas levels at seven points in a silo during fumigation of 1420 tonnes of wheat, with five blankets hung in the silo top headspace. With no gas recirculation it took four to five days for gas to reach all grain at the silo base.**




Source: Philip Burrill and Andrew Ridley

A small fan can recirculate and rapidly distribute phosphine gas around larger silos during fumigation.

### KEEPING IT SAFE

Check the product label for venting time. This is usually 24 hours if aeration fans are fitted to force a draught through the silo. It is usually five days for storages without fans, which rely on passive venting.

Storage enclosures and work areas need to be vented to below the time-weighted average (TWA) exposure standard of 0.3ppm for phosphine. Use fumigation warning signs and red and white safety tape on any storage under fumigation.

Take the time to read the restraints and safety sections on phosphine product labels. For example, labels explicitly prohibit use in road transport vehicles, including a truck or road-hauled container. This is to prevent the practice of placing phosphine tablets in loaded grain trucks prior to delivery, which was common decades ago. ☐

**GRDC Codes PRB2011-001SAX, NPB00013**

**More information:** Philip Burrill, 1800 WEEVIL, info@storedgrain.com.au

# When to open sealed silos

## Outside fumigation, there is no need to seal a silo – in fact, sealing a silo for long periods increases the risk of grain degradation and silo damage

**By** Ben White and Chris Warrick

### KEY POINTS

- Gas-tight sealable silos should meet the Australian Standard AS2628-2010 for sealing but should only be sealed during a fumigation
- Open sealed silos after fumigation to protect seals and grain quality and, importantly, to prevent excess fumigant absorption

There is a common misunderstanding that silos seal as a physical barrier to prevent insects getting into the grain. But silo seals and the Australian standard for sealing (AS2628-2010) are only designed to keep fumigant in the silo long enough to ensure successful fumigation with an adequate fumigant concentration for insect control. So, what should be done with gas-tight sealable silos when they are not under fumigation?

### WHEN TO SEAL?

A silo that meets the Australian Standard AS2628-2010 provides the buyers of gas-tight sealable silos with confidence they will get what they are paying for.

These silos will pass a five-minute, half-life pressure test when new. The half-life pressure test is a reliable method to ensure the silo will hold fumigant at an adequate concentration for the time required to control all life stages of stored grain insect

Photo: Ben White

Gas-tight sealable silos are important when trying to kill all life stages of insect pests inside. But they need to be allowed to breathe after fumigation to minimise damage to seals and structure and maintain grain quality.

pests – egg, larvae, pupae and adult.

Where a silo has been on-farm for some time, passing a three-minute, half-life pressure test should still provide adequate fumigant retention for insect control.

When ordering gas-tight sealable silos, ask the manufacturer to guarantee and include reference to AS2628 on the invoice, and insist a pressure test be demonstrated on delivery or construction.

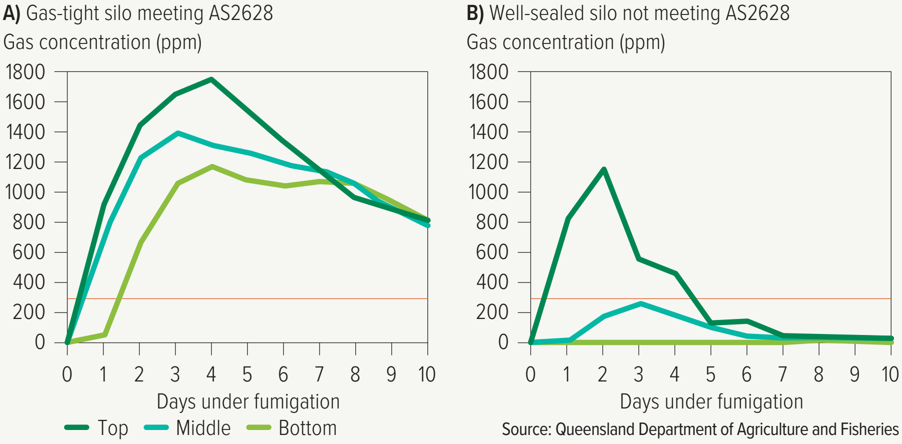
## THE IMPORTANCE OF THE SEAL

Queensland Department of Agriculture and Fisheries research, undertaken with GRDC investment, examined the variation in fumigation performance of two seemingly identical silos. Silo A passed a three-minute, AS2628 half-life pressure test. Silo B had slightly compromised seals, and could be pressurised, but was unable to meet the three-minute half-life pressure level to pass the test.

Silo A maintained more than 300 parts per million (ppm) of phosphine in all areas of the silo for seven days, as required to provide effective control of all insect life stages, including eggs and pupae (Figure 1A).

Silo B failed to maintain 300ppm for seven days and was unable to reach 300ppm in the middle or bottom of the silo (Figure 1B). Many insects would have survived the fumigation in silo B but, more alarmingly, fumigations in silos like this add to the growing issue of pests becoming resistant to fumigation gases.

**Figure 1: Silo A, which met fumigation performance standards, maintained more than 300 parts per million (ppm) of phosphine in all areas of the silo during a seven-day test, as required to provide effective control of all insect life stages, including eggs and pupae. Silo B had slightly compromised seals and was unable to pass performance tests, maintain 300ppm for seven days or reach 300ppm in the middle or bottom of the silo.**




Source: Queensland Department of Agriculture and Fisheries

## WHEN TO OPEN?

There are three primary risks with sealing silos for extended periods of time: grain degradation, structural damage and excess fumigant absorption.

When not fumigating, leave silos unsealed to allow free air movement. Air in the headspace, for example, can be very warm and carry considerable moisture. Allowing this to escape lowers the temperature of the grain in the headspace and minimises spoilage of the top layer of grain.

Structural damage or deterioration of seals can occur if the weather changes suddenly and the air inside the silo expands or contracts rapidly.

A pressure relief valve is fitted to gas-tight sealable silos to minimise the impact of rapid temperature changes by letting some air in or out if the differential pressure is too great during a fumigation. By design, the valve provides this safety measure without compromising the concentration of fumigant when the silo is sealed for fumigation.

But during rapid temperature changes, the volume of air to exchange can be more than the pressure relief valve can handle, putting the pressure seals at risk of damage. The most obvious way to avoid this is to leave the silo unsealed when not fumigating. This issue is exacerbated when partially filled silos are sealed, leaving a greater volume of air in the silo to expand or contract.

If partially filled silos need to be sealed for fumigation, the weather forecast should be monitored for rapid changes, including a cool front or a storm on a hot day.

Protect silo seals by ensuring the pressure relief valve and any piping to the headspace is of adequate size for the silo. For large (more than 750 tonnes) flat-bottom silos, two or more pressure relief valves are typically required.

## LONG-TERM SEALING RISKS

Contrary to any past advice, growers should not leave silos sealed after fumigation. This practice is off-label and can lead to grain absorbing high levels of phosphine.

The label requirements for venting and withholding provide adequate time for any absorbed phosphine to be desorbed. But if grain is fumigated for more than the fumigation period prescribed by the label, additional phosphine can be absorbed, which will require a longer time for desorption.

This can create issues at delivery points where highly sensitive detection equipment is increasingly being used to identify the presence of phosphine gas.

If silos are sealed soon after filling, warm and potentially moist grain can produce condensation in the headspace, which will drip down the walls onto the grain, causing mould and grain spoilage.

Leave silos open to vent and breathe, without letting rain in, to avoid this issue. Use a vent that can be sealed for fumigation or, alternatively, lock the lid in a partially open position to vent while keeping the weather out.

Ideally, cool grain with aeration fans to create uniform moisture and temperature conditions to help prevent mould and insects. ☐

THERE ARE THREE PRIMARY RISKS WITH SEALING SILOS FOR EXTENDED PERIODS OF TIME: GRAIN DEGRADATION, STRUCTURAL DAMAGE AND EXCESS FUMIGANT ABSORPTION.

**GRDC Code PRB2011-001SAX**

**More information:** Ben White, 1800 WEEVIL, info@storedgrain.com.au

# Getting the most out of ground-level fumigation

**Ground-level fumigation offers safety benefits to growers but takes a new set of skills to get right**

**By** Chris Warrick

## KEY MESSAGE

Ground-level fumigation systems are safer for users but phosphine can be explosive, so precautions are needed to ensure a safe and effective fumigation.

Phosphine fumigation can now be completed using ground-level application systems, which are much safer as the user does not need to climb to the top of the silo. But some key features and precautions are needed for successful and safe fumigation:

- recirculation;
- space for liberation;
- condensation trap; and
- pressure relief for power outage.

Phosphine needs space to disperse safely. For ground-level application, a recirculation system is essential to improve the rate of phosphine flow through the silo and prevent an explosion in the confined application chamber.

Without airflow, phosphine moves through grain at roughly six metres per 24 hours, according to Queensland Department of Agriculture and Fisheries research. This means it could take several days for gas concentrations to reach lethal levels in all parts of a large silo. A sealed recirculation system will transfer air from the head space in the top of the silo back to the bottom of the silo, or vice versa, to reduce the time taken.

## RECIRCULATION SYSTEMS

There are two types of recirculation – active (powered) or passive (thermosiphon). Active systems include a powered fan to move air in the closed loop system. Passive recirculation relies on thermal currents to transfer air through pipes up the outside of silos, often referred to as thermosiphons. Active or powered recirculation is necessary for silos larger than 150 tonnes and is the preferred option for smaller silos.

A key criterion for recirculation is that the plumbing does not compromise the sealability of the silo, now or into the future. This requires quality pipe with solid fittings and mounts.

For passive or thermosiphons, the pipe size needs to be large. Research commissioned by the Council of Grain Grower Organisations found that a 90-millimetre thermosiphon pipe on a 6m-high silo moved 1800 litres of air per 24 hours. Any restriction through pipe fittings, transitions or smaller pipe is inadequate for ground-level application.

As phosphine liberates (changes from a solid to a gas) the concentration can reach explosive levels in a confined space. This is exacerbated during humid weather if the grain in the silo is high in moisture or moisture is added to or near the phosphine – an unnecessary and extremely dangerous practice.

To improve safety, maximise both the space for phosphine to liberate and the airflow in the sealed system to carry gas out of the application chamber and into the silo.

## SAFETY FIRST

Condensation will inevitably run down the inside of the recirculation pipe. Ground-level application chambers should be positioned off to the side of the main vertical pipe to enable condensation to run past the chamber, where it can be drained after the fumigation is complete. If condensation runs on to the phosphine it will liberate too quickly, potentially reaching explosive levels, and lead to a short period of high gas concentration rather than a sustained period of the required gas concentration.

While the application chamber in a thermosiphon needs to be positioned to the side of the vertical pipe, the pipe connecting it to the bottom of the silo needs to be on the opposite side of the chamber to ensure airflow goes through, rather than past, the chamber.

If power is cut to active or powered recirculation systems during a fumigation, gas concentration in the chamber could soon reach explosive levels. These systems require an uninterruptable power supply and a safety pressure relief to ensure that, if the application chamber does explode, it does so in a way that does not involve steel fragments flying in all directions. ☐


Photo: Chris Warrick

Ground-level application systems require a sealed recirculation system with large-enough pipe to ensure liberated gas can freely flow into the bottom and headspace of the silo.


Photo: Chris Warrick

Powered recirculation systems produce even gas distribution in large, flat-bottom silos, avoiding areas of sub-lethal gas concentrations.

**GRDC Code PRB2011-001SAX**

**More information:** Chris Warrick, 1800 WEEVIL, info@storedgrain.com.au

# Local study breathes fresh air into grain aeration

## New testing set to reveal back pressures for Australian grain under aeration

**By** Ben White and Alex Conway

Photo: Alex Conway

Grain aeration is a valuable tool for growers storing grain on-farm, but more information is needed to help growers ensure flow rates are effective in Australian storage scenarios.

### KEY POINTS

- Existing back-pressure data for aerating grain was largely developed in the Northern Hemisphere via studies that date back as far as the 1950s
- Flow rates vary depending on the back pressure exerted by different grain and storage systems
- A prototype test rig is under development to enable testing of local storage systems

■ Achieving sufficient airflow is essential for effective grain aeration, and back pressure – the resistance to airflow through the grain – is one of the important variables determining success. But much of the information used to determine aeration back pressure is outdated and was generated under Northern Hemisphere conditions.

To understand whether flow rates are sufficient to achieve cooling or drying, growers need to understand back pressure and fan performance curves, which can be difficult to find. To address these gaps, GRDC investment through the 'Grain Storage Extension Project' is evaluating Australian systems.

### UNDERSTANDING AIRFLOW

Grain aeration can be used to reduce grain temperatures or moisture content, making it a valuable tool to protect stored grain from deterioration and insect pests.

Aeration cooling has the potential to drastically reduce insect pest reproduction rates as well as preserve grain quality and germination. Aeration drying reduces grain moisture content to provide safe long-term storage of the commodity.

Typical aeration flow rates required for aeration cooling are about two to four litres per second for each tonne of grain in storage. Aeration drying requires much higher flow rates of between 15 and 20L/s/t.

Aeration fans are not typically supplied with performance curves, as performance depends on many factors including fan design and the ducting chosen to take air from the fan and diffuse it through the grain. When the fans are operational, the back pressure – or static pressure – exerted by the grain also plays an important role.

Back pressure depends on many factors including:

- the type of grain and its physical properties, such as moisture content, size and shape. For example, aerating canola generates significantly more back pressure than larger, coarse grains such as sorghum and maize;
- the airflow rate – back pressure increases as the flow rate increases; and
- the depth of grain – the relationship between depth and back pressure is relative, with higher silos having higher back pressure for the same airflow rate.

### AUSTRALIAN TESTING

A comprehensive literature review of available information revealed that much of the currently referenced information relies heavily on research work done as far back as the early 1950s.

It also identified that almost all of the relevant back-pressure research to date has been conducted in the Northern Hemisphere, focused on grains, varieties and airflow rates that may not be suitable for the Australian situation.

These findings are disconcerting, but helpfully the review identified several methods of determining back pressure that will help the Australian team develop test equipment capable of capturing back-pressure data under a range of airflow rates and grain depths.

The next stage involves the design and prototyping of a modern test rig to capture back-pressure data. Based on similar test equipment identified in the literature review, the rig will be adapted to suit Australian grains and airflow rates used under typical grain storage environments.

The rig will use high-precision instrumentation for measuring back pressure and airflow, with variable-speed, brushless, DC-driven, backward-curved blowers to push air through columns of a range of grains.

Results generated with the grain types typically stored in Australia will enable the team to ground-truth the local relevance of the existing data from the Northern Hemisphere. The research will also explore back-pressure data for crops more traditionally grown in northern Australia, including sorghum, mungbeans, soybeans and maize. □

**GRDC Code PRB2011-001SAX**

**More information:** Ben White, 1800 WEEVIL, info@storedgrain.com.au,

Utilising aeration cooling in grain storage youtu.be/UHowXep5VWE

# Top tips for grain storage success

## Take a sneak peek at some of the storage extension team's favourite systems

By Ben White and Chris Warrick

■ GRDC's grain storage extension team regularly meets growers and industry participants on-farm to run workshops and provide specialist advice. Examples of well-laid-out facilities, smart features, ideas and innovations are highlighted here to help inspire other growers who are investing in grain storage infrastructure. □

**GRDC Code PRB2011-001SAX**
**More information:** 1800 WEEVIL, info@storedgrain.com.au

Photos: Chris Warrick and Ben White

### SCALED UP


Figure 1: Two new 12,000-tonne silos dominate the skyline at the Candeloro family farm at Toodyay, Western Australia.
The new additions increase the already sizeable facility to 64,000t of gas-tight sealable storage and utilise the existing in-loading tower.
Aeration cooling systems are fitted to all the silos in the facility and are sized to deliver two to four litres per second per tonne of cooling air.
Twelve high-efficiency brushless electronically commutated (EC) motor-driven fans drive cooling air through the grain stack in both the new silos.

### ROOM TO MOVE


Figure 2: Trucks' capacity and length are increasing.
Make sure hardstands can accommodate the turning circles of the largest of today's trucks, with some room for expansion in the future. This should be reviewed if the facility is to be constructed in stages or with a mix of storage types.

### TAKING A BREATHER


Figure 3: When buying silos, look for pressure relief valves that are clear or semi-opaque so that oil levels can be adequately maintained and topped up if required with light hydraulic oil.
Clear or semi-opaque pressure relief valves can also be used for pressure testing to determine the suitability of the silo for fumigation.

## HITTING THE HEIGHTS


Figure 4: Access to the inlet and head space is required to monitor the condition of grain in storage and to take samples when inspecting for insect pests. Access is also useful when undertaking maintenance and repairs of the inlet and inlet seals to maintain gas-tight sealable status, particularly if bumped or damaged by the auger or conveyor when in-loading.
Silos should be ordered with quality ladders or staircases to ensure access to the inlet.
Where a line of silos is installed, a single ladder with a rooftop walkway and handrails may reduce costs while providing convenient access to numerous silos (Figure 4A).

## DELIVERING THE DRAFT

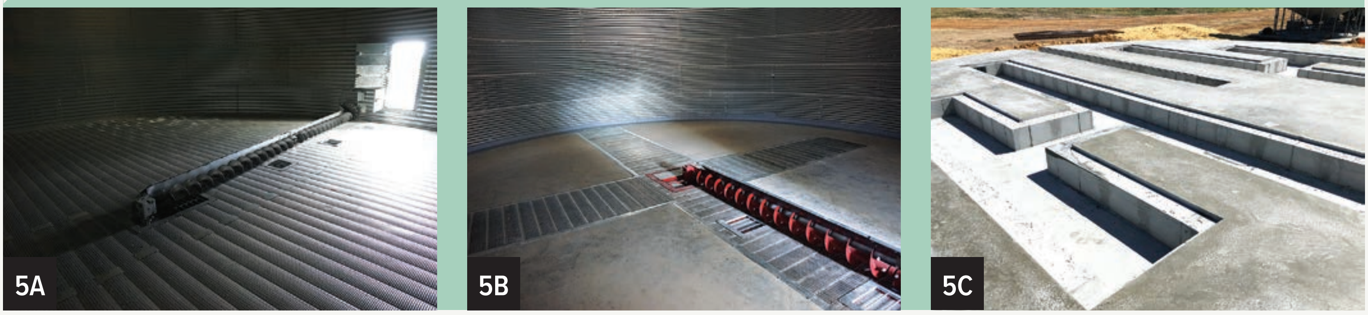



Figure 5: Aeration systems in large flat-bottom silos come in either full floor (Figure 5A) or trench delivery of air (Figure 5B).
With full-floor aeration, air flows through a false, permeable floor over the pad, while trench aeration has trenches formed into the pad to channel aeration (Figure 5C).
Each system has benefits and disadvantages. Full-floor aeration offers the most even delivery of air throughout the silo but is more difficult to clean, requiring the floor sections to be lifted and removed to clean out all traces of grain dust to prevent insect infestation.
Trench aeration requires careful planning of the trench position for maximum uniformity of air delivery.
While trench air delivery cannot match the uniformity of a full-floor aeration, a thorough clean-out is simpler, requiring only the trench screens to be lifted and the trenches cleaned out.

## BOGAMILDI BRILLIANCE


Figure 6: The 4600t Manchee facility at Bogamildi, near Moree, NSW, is a clever design that minimises the need for cleaning.
Storage comprises two recently constructed flat-bottom 1500t silos and eight elevated 200t cone-base silos (Figure 6A).
The site is well-laid-out with a weighbridge and outer drive around the silos (Figure 6B).
A permanent out-load point is fed via a series of belted conveyors running under the elevated cone base silos (Figure 6C).
The belts extend back to the flat-bottom silos and, in the future, will be extended back to another pair of large flat-bottom silos.

Bunkers had the capacity John Stevenson needed to make dramatic improvements to harvest logistics at 'Orange Park', Lockhart, NSW.

Photo: John Stevenson

# Boosting on-farm storage with bags and bunkers

## With care, bags and bunkers can provide a practical solution to the harvest logistics challenge

**By** Katherine Hollaway

High-quality sealed silos offer top-of-the-range storage, but the boom in demand for on-farm storage means growers are also exploring cheaper options to expand capacity.

Bags and bunkers have become a popular, more affordable choice, but growers need to be on their toes to avoid costly failures with these temporary storage solutions.

Some growers have lost significant quantities of grain using bags. The problems are mostly associated with grain storage over the winter period where rainfall runs down the sides of the silo bag and enters the bag through perforations causing sprouting.

### HARVEST LOGISTICS

Simon McRae introduced bags in 2020 as temporary storage to improve harvest logistics, and he plans to use them again. He grows wheat and canola with some barley and vetch hay on 6500 hectares with his wife Marita and adult daughters at Temora, New South Wales. The bags were used for short-term storage and all emptied before sowing.

"At harvest we run headers 24 hours a day and use every bit of storage we have to keep the headers going after the truck drivers finish for the night. The bags offer real flexibility when paddocks are spread 30 or 40 kilometres apart or for storing on land that we've leased. We can unload right there in the paddock.

"We found the protein monitor on the header really useful to give us a record of the total tonnage and average protein and moisture content for each bag."

Controlling vermin is a top priority and the family bait extensively as soon as the bags hit the ground. "We want to prevent the mice from finding it – they start chewing the bags, then the foxes arrive and it's a vicious cycle.

"We had one issue where moisture penetrated along the bottom of the bag, which made it more difficult to unload, demonstrating how important it is to get the location right."

### BAG A BARGAIN

Veteran bag user Iain Tyack has used up to 50 or 60 bags a year. He says they were a cheap way to store grain on-farm and

## "Bags offer real flexibility when paddocks are spread 30 or 40 kilometres apart or for storing on land that we've leased." – SIMON MCRAE

When used with care, grain bags can provide a flexible and affordable option for short-term storage.

Photo: Brad Collis

improve logistics when he started out at Condobolin, NSW, 15 years ago. Iain and his wife Jenny and their adult children, who grow 3000ha of wheat and barley, mostly use the bags over the summer, but on occasion for up to three years.

While their silo capacity has increased, they still use a few grain bags to meet demand in a better season.

Iain's advice to new users is to find the right site. "A bit of fall end to end is important – about half a bubble on the spirit level. If the bags are laid sideways to the slope they will act as a weir and any tiny pinprick from stubble can be an entry point for moisture. Clear ground is best, but tall stubble is less likely to cause damage than chopped stubble."

They also site bags at least 15km away from rivers to limit problems with birds and pigs. To protect against birds for longer-term storage, they cover the bag with old tyres with an old bag on top and use a reflective scaring device.

### HANDLING THE VOLUME

In 2020, Warakirri Cropping manager John Stevenson knew he was going to have to make some dramatic improvements to harvest logistics. A change to stripper fronts that increased harvest capacity by 50 to 60 per cent had combined with a bumper harvest at the 8000ha 'Orange Park' at Lockhart, NSW. John says they had been struggling to get grain away in previous seasons with limited local delivery options.

"Bunkers had the capacity we needed, and we were lucky to be able to outsource their management to our grain carrier. We do the groundwork and they take care of the rest. With multiple sites on-farm there are no queues and no delays, plus we've improved our carrier's logistics by reducing the number of trucks they need."

The bunkers are mainly used for cereals, because they are harvested quickly and have the volume to fill a bunker properly, with a good peak on top for runoff. Canola and pulses are stored in silos to protect quality and because of their smaller volumes and slower harvest times.

John says that a well-laid-out site is vital for good traffic flow and to make sure water runs off.

"We've had some issues with mice. There were no problems where the edges of the tarps were sealed with sand, but the mice were able to dig through when we used crusher dust."

### FULL CONTROL

Nils Jacobson favours bunkers as cheap and flexible storage that put him in control of grain marketing. The Lawson Grains manager at 'Uah' – 10,500ha at Forbes, NSW – stores the entire season's marketable harvest in on-farm bunkers. Only seed retained for sowing is put into silos.

"We hadn't planned on storing this much when we started in 2016, but with only one receival option in Forbes, bunkers proved too convenient. Wheat, barley and chickpeas are often held for 11 months, but we usually sell canola by April. We have held chickpeas in bunkers for up to two years when markets were limited," he says.

"A suitable, well-drained location is more important than a central location.

"The next thing is good access for trucks – we had a real challenge with vehicles getting bogged in 2021 when trying to move grain out."

Nils' top tips are getting the dome shape right, using good-quality tarps and sealing them well. "It's mostly about taking the time and having the people you need to get it set up properly at harvest time. We still get some leakage at the stitches where we join the tarps and we are experimenting with sealing options.

"Every season is different; we continue to learn and evolve. We plan to upgrade to silos for canola and chickpeas and are experimenting with TeleSense monitors to get a better understanding of temperature and moisture in the bunkers." □

**More information:** Simon McRae, 0428 145 891, simorty1@bigpond.com; Iain Tyack, 0429 729 181, nootyack@hotmail.com; John Stevenson, 0429 206 238, john.stevenson@warakirricropping.com.au; Nils Jacobson, 0455 039 009, uah@lawsongrains.com;

GCTV Extension Files: Grain Bags – best practice youtu.be/Ab-A2Il6b1Q, Considering temporary grain storage? Bunkers are an option youtu.be/Uv1hdXBBXaE

# Phosphine venting and delivery limits require more research

Photo: Chris Warrick

The practice of requiring a phosphine gas reading of less than 0.3ppm in a spear sample taken from within the grain threatens costly rejection of truckloads of grain, including for operators who are following phosphine label directions.

**By** Philip Burrill, Dr Greg Daglish, Dr Manoj Nayak and Dr Raj Jagadeesan

## KEY POINTS

- Testing phosphine residue in trucks at receival sites is required for operator safety and label compliance
- Sampling and testing methods require further research and development to avoid penalising those doing the right thing
- Using a phosphine meter on farm is the surest way to avoid truckloads being rejected

There is no argument that testing grain deliveries for phosphine residue is needed to ensure operator safety and label compliance. However, some preliminary research has revealed more work is needed to develop an appropriate testing protocol. Without further development, the current testing method used at some grain receivals threatens costly rejection of truckloads of grain, including for operators who are following phosphine label directions.

The Safe Work Australia standard for phosphine exposure is 0.3 parts per million (ppm) time-weighted average (TWA), referring to the air people are breathing over an eight-hour workday and 40-hour week.

The current test method used by some receival sites involves a spear sample into the grain requiring a phosphine reading of less than 0.3ppm. The difference is that TWA gas concentrations are taken in the air operators breathe, rather than from within the grain stack.

The phosphine label also states that "ventilation of structures is complete only when the phosphine concentration measured at appropriate locations in the enclosure and work area are below TWA exposure standard of 0.3ppm".

To ensure operator safety, further research is needed to compare gas concentrations from the air within the grain bulk versus the air that operators breathe. Appropriate gas concentrations at these measuring points need to be identified.

## PRELIMINARY RESEARCH

Phosphine fumigation trials conducted by Queensland Department of Agriculture and Fisheries (DAF) in 2019 explored the relationship between phosphine gas concentrations trapped in the air between grain after venting and the gas levels that someone could potentially breathe at the grain surface.

After a 10-day fumigation and 24-hour fan ventilation (as per label directions), phosphine gas measurements were taken at a depth of one metre in the grain using a gas probe. A second test measurement was taken at the grain surface.

Results showed that phosphine gas concentrations from the 1m probe within the grain were as high as 1.4ppm after venting (Figure 1). In contrast, gas concentrations on the grain surface were much lower at 0.06ppm, well below the threshold limit value – time-weighted average (TLV-TWA) of 0.3ppm.

These results indicate that further industry-based research and development is required to clarify the relationship between gas levels measured when probing grain in trucks and gas levels measured in air that workers are breathing. Gas readings taken within a grain bulk are significantly higher than the levels present at the grain suface, let alone what might be measured where workers are operating. This preliminary data suggests TWA sampling locations need to be reviewed to ensure a safe working environment without unnecessarily rejecting grain deliveries and potentially penalising operators who are performing successful fumigations and venting as per the label directions.

## VENTING BELOW 0.3PPM

Research conducted by DAF in 2017 revealed that the label-directed ventilation period of five days, or one day with aeration fans, is unlikely to exhaust phosphine below 0.3ppm in a grain spear sample.

After a seven-day fumigation and 24-hour ventilation using an aeration fan, gas measurements were taken within the grain bulk at the top, middle and bottom of the silo for the following eight days. While the measurements taken immediately after the aeration-assisted ventilation were low, they quickly rose back up from 0.8 to 2.0ppm within 24 hours (Figure 2).

Augering the grain out and back into the silo to replicate outloading and delivery temporarily reduced the gas readings. But the gas concentration again rose from 0.2 to 1.2ppm before declining below the target 0.3ppm four to five days after ventilation.

## AVOIDING REJECTION

Until further research and development is done by industry, growers who deliver to sites using a 0.3ppm gas limit measured within the grain stack may need to extend their ventilation periods by at least four days.

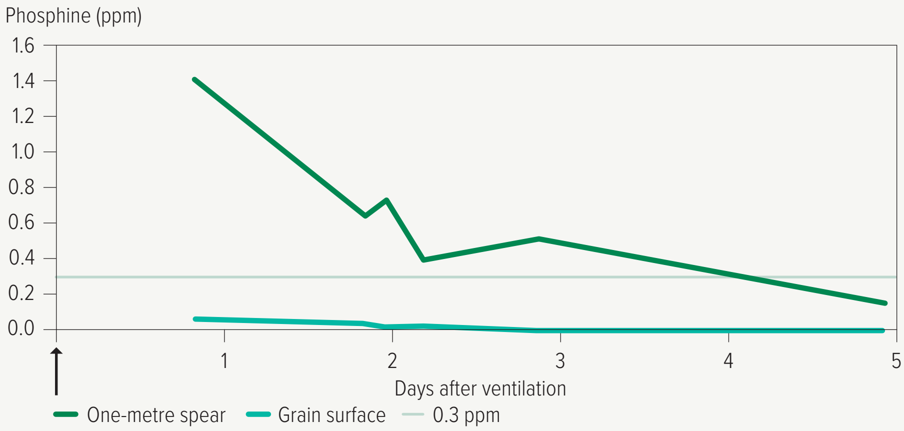
Venting time might need to be increased when the grain is cold, when the fumigation exposure time was extended beyond label directions or in storages without aeration fans or with limited vent openings, such as large silos and grain bags.

To ensure compliance and avoid truckloads of grain being rejected, growers can use phosphine meters – Drager Pac 8000 or Silo Safe – to measure gas concentrations within the grain stack before outloading. Ensure measurements are taken at least 24 hours after aeration fans are turned off or grain has been moved to avoid a false low reading. ☐

**GRDC Codes PRB2011-001SAX, NPB00013**

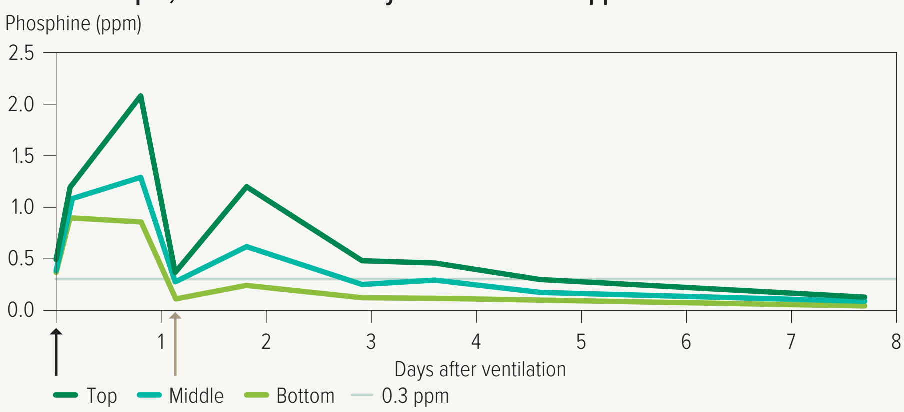
**More information:** Philip Burrill, 1800 WEEVIL, info@storedgrain.com.au; Drager Pac 8000 from Graintec www.graintec.com.au; Silo Safe from Canary www.canaryco.com.au

**Figure 1: Phosphine gas measured at the grain surface versus a one-metre spear placed into the grain stack. The black arrow shows when ventilation was completed. The trial consisted of a 10-day fumigation period followed by 24-hour ventilation with aeration fan. Grain was augured out and back into the storage two days after ventilation was completed.**




Source: Queensland Department of Agriculture and Fisheries

**Figure 2: Phosphine gas measured at three points within the grain bulk in a silo following a seven-day fumigation and 24-hour ventilation with aeration fan. The black arrow shows when ventilation was completed. The brown arrow shows the temporary drop in gas readings after the grain was augered out and back into storage. What is evident is that grain slowly desorbs phosphine over time and, in this example, took four to five days to fall below 0.3ppm.**




Source: Queensland Department of Agriculture and Fisheries

# Users must heed rising phosphine resistance

## Tracking stored grain insect populations over the past decade shows how quickly and widely strong resistance to phosphine has increased

**By** Dr Jo Holloway, Dr Manoj Nayak and Dr Oonagh Byrne

### KEY POINTS

- **Strong resistance to phosphine in stored grain insects has both increased and spread over the past decade, with more detections in eastern Australia than Western Australia**
- **Misuse of phosphine, particularly in unsealed storages, appears to be the main reason for the development of strong resistance**

Australian growers have relied heavily on phosphine fumigation to disinfest stored grain and meet market expectations for high-quality grain with nil tolerance to insects. However, reliance on one chemical over a long period of time has led to resistance.

### SURVEYING RESISTANCE

Since 1996, GRDC's 'National Phosphine Resistance Monitoring' project has monitored resistance to inform research and develop strategies to help growers protect the reliability of phosphine fumigants.

Rusty grain beetle, one of the flat grain beetles, was not the first insect pest in Australia to develop strong resistance to phosphine. But when a resistant population was first detected in NSW in 2007, it had the strongest level of resistance to phosphine anywhere in the world and could not be controlled with the label rate.

Resistance is more common in eastern Australia, where the proportion of strong resistance has increased in the five major stored grain insect pests over the past 10 years (Figure 1A). When all species are combined, it has increased more than fivefold – from 1.8 per cent (mid-2000 to mid-2011) to 9.6 per cent (mid-2011 to mid-2021). The lesser grain borer has the highest proportion of strong resistance, at 11.7 per cent.

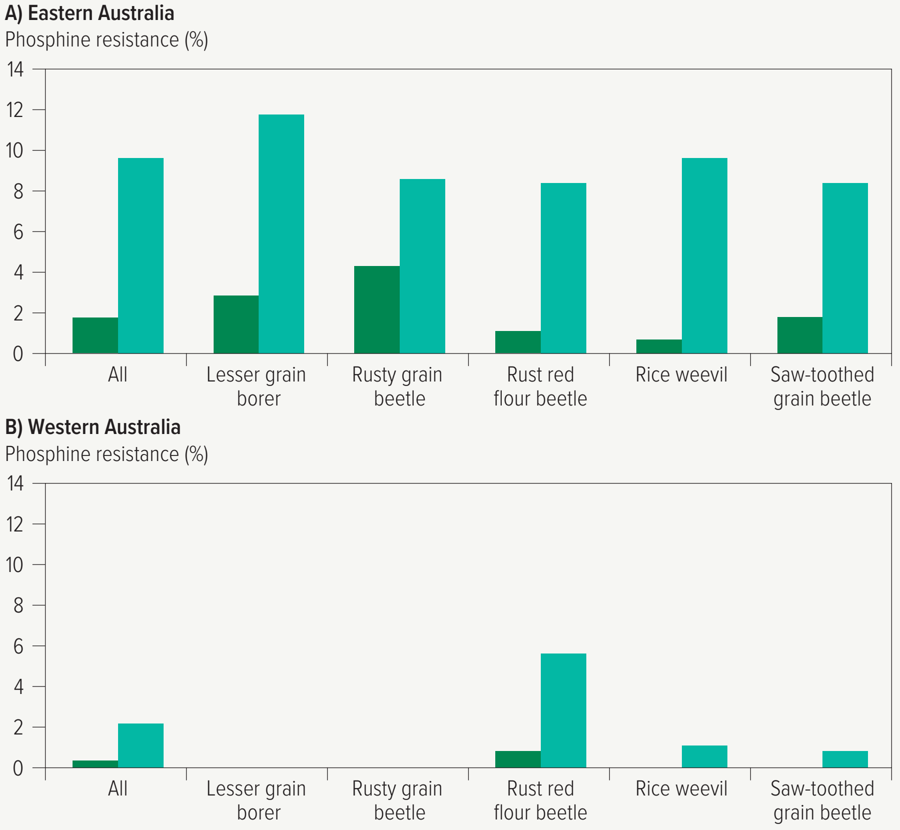
In Western Australia, the percentage of populations with strong resistance has also increased by five times, from 0.4 per cent (mid-2000 to mid-2011) to 2.2 per cent (mid-2011 to mid-2021) (Figure 1B).

Prior to 2011, strong resistance to phosphine on farms in WA was only detected in the rust red flour beetle. Since then, strong resistance has also been detected in the rice weevil and saw-toothed grain beetle, although these populations were quickly contained.

### PREVENTING SPREAD

Strong resistance to phosphine can develop and spread quickly. Resistance in stored grain insects has now spread throughout the grain growing regions in all states, with the greatest increases observed in South Australia (Figure 2).

**Figure 1: The proportion of stored grain insect populations with strong resistance to phosphine collected from farms mid-2000 to mid-2011 and mid-2011 to mid-2021 in A) eastern Australia and B) Western Australia.**




Source: Dr Jo Holloway

For example, after its first detection in 2007, rusty grain beetle had spread to four farms by 2011 – in NSW and South Australia. However, by 2021 it had spread to Queensland and Victoria, with a total of 53 detections across eastern Australia.

While the expansion of surveys into new regions, such as Townsville, can explain some of the increased spread, the main culprit is the misuse of phosphine – particularly in unsealed storages.

Phosphine requires time to be effective against all life stages, particularly eggs, and should only be used for grain fumigation in gas-tight storages.

Phosphine is a particularly mobile gas and concentrations fall below recommended levels when used in non-gas-tight structures. Practices such as use in unsealed storage, storing grain for longer durations and incomplete cleaning of storages all increase the risk of insect infestations requiring control. Multiple poor fumigations of the insect populations can result in resistance.

Storage seals deteriorate over time, leading to gas leakage. Growers need to maintain sealed storages and pressure test prior to fumigation. Monitor grain for insects, particularly after a fumigation and, if found, send them to the nearest laboratory for resistance testing and advice.

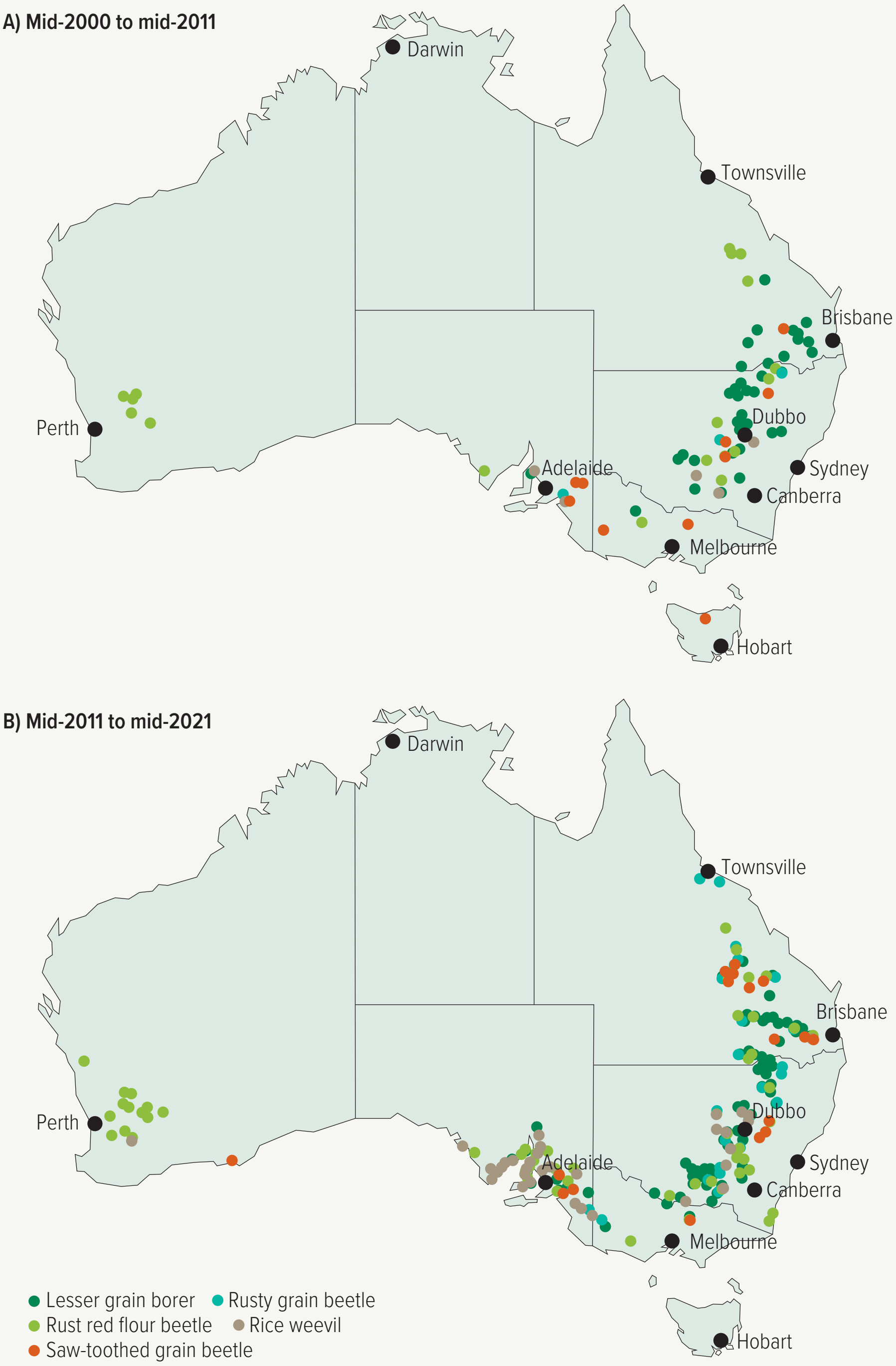
The 'National Phosphine Resistance Monitoring' project is led by the Queensland Department of Agriculture and Fisheries, in collaboration with the NSW Department of Primary Industries and the Western Australian Department of Primary Industries and Regional Development. □

**GRDC Code DAQ1906-002RTX**

**More information:** Dr Jo Holloway, 0410 410 736, joanne.holloway@dpi.nsw.gov.au

GCTV7: Overcoming Phosphine Resistant Insects youtu.be/g-AABMqMf_w

**Figure 2: Locations of stored grain insect populations collected from farms A) mid-2000 to mid-2011 and B) mid-2011 to mid-2021 with strong resistance to phosphine.**




Source: Dr Jo Holloway

**Practices such as use in unsealed storage, storing grain for longer durations and incomplete cleaning of storages all increase the risk of insect infestations requiring control. Multiple poor fumigations of the insect populations can result in resistance.**

# Probing phosphine resistance in rusty grain beetle

## Increasing phosphine resistance in rusty grain beetle requires a new approach: area-wide integrated pest resistance management

**By** Dr Raj Jagadeesan, Dr Manoj Nayak, Dr Gregory Daglish and Philip Burrill

Rusty grain beetle (*Cryptolestes ferrugineus*), one of the flat grain beetles, is a serious threat to Australia's reputation as a provider of insect and residue-free grain. High levels of resistance to the fumigant phosphine – up to 1200 times in some populations in Australia – is rendering label rates ineffective.

A better understanding of the geographic spread of resistant populations and the genetic basis for resistance has the potential to guide the development of effective region-specific integrated pest and resistance management practices.

The Queensland Department of Agriculture and Fisheries has coordinated analysis of resistant populations of rusty grain beetle throughout eastern Australia. Complementary research programs were conducted in collaboration with the NSW Department of Primary Industries through GRDC investment and with the University of Queensland as part of the Australia-India Strategic Research Fund. This research has painted an intricate picture of increasing levels of resistance throughout the grain value chain, including on-farm.

Researchers collected 365 grain samples from bulk handling companies, 136 from farms, 105 from contract storages and 50 from other stakeholders – such as seed merchants and feed mills – during three seasons from 2017-18 to 2019-20.

### RESISTANCE FREQUENCIES

When resistant populations were first identified in 2007, the rate of incidence was about five per cent and populations were mainly confined to bulk handlers, where the vast majority of grain was stored.

But the increasingly diversified market means larger quantities of grain are being stored on-farm and by other stakeholders – and over longer periods. This has led to an increase in the number of phosphine fumigations per storage site each year. The rusty grain beetle's ability to fly over large distances and infest multiple commodities has compounded the resistance challenge.

Results from the latest study showed that nearly 50 per cent of the samples collected from bulk handlers, farms and other stakeholders contained rusty grain beetle infestations, but only 17 per cent of contract storages were infested (Figure 1).

Resistance testing of samples which contained beetle infestations using laboratory assays showed that strongly resistant insects exist throughout the supply chain in the range of 22 to 46 per cent (Figure 2).

Molecular DNA testing showed that many individuals in the populations harbour a single copy of the resistance gene and express partial resistance. This happens when susceptible and strongly resistant populations mate and produce offspring. The overall incidence of resistance genes in the population was higher than the proportion of fully resistant individuals, suggesting potential future increases in the frequency of resistant populations.

### AREA-WIDE STRATEGIES

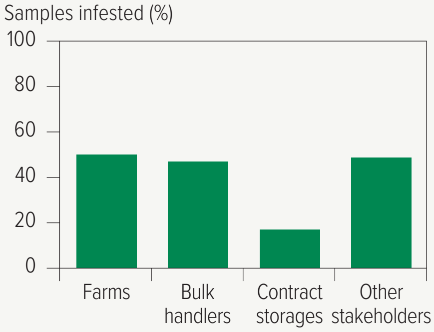
The discovery of widespread resistance throughout the value chain, and the high mobility of the rusty grain beetle population, makes it clear that a coordinated management approach is required for each region. Research will now focus on the development of area-wide integrated pest and resistance management (AW-IPRM) strategies. The AW-IPRM concept dates back to the 1990s and has proven successful in managing several field insect pests.

The approach relies on coordinated suppression of the majority of the pest population (90 per cent) across multiple sectors in a region, rather than near eradication of the total population (99 per cent) at a single sector or a site, and it has the potential to keep the pest population below economic thresholds indefinitely.

Photo: Dr Raj Jagadeesan

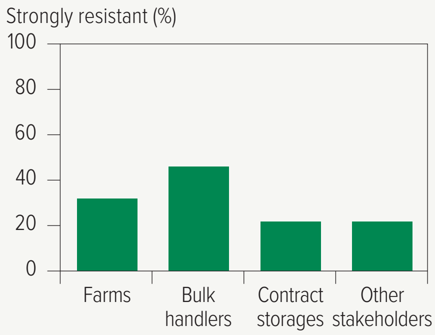
**Resistant rusty grain beetles, one of the flat grain beetles, have been found throughout the grain supply chain, suggesting the need for adoption of area-wide integrated pest and resistance management.**

**Figure 1: Percentage of grain samples infested by rusty grain beetle at different storage sites in the grain supply chain from 2017 to 2020.**




Source: Dr Raj Jagadeesan

**Figure 2: Percentage of strongly resistant rusty grain beetle detected in the samples, which contained beetle infestations, that were collected from different storage sites in the grain supply chain from 2017 to 2020.**




Source: Dr Raj Jagadeesan

Suitable integrated pest resistance management strategies combine non-chemical and chemical pest management tools. These include aeration and grain cooling, restricting phosphine fumigations to sealable gas-tight silos with strict adherence to label rates, rotating phosphine with sulfuryl fluoride – a phosphine resistance breaker – and using grain protectants or diatomaceous earth wherever possible. ☐

**GRDC Code DAQ1906-002RTX**

**More information:** Dr Raj Jagadeesan, 0401 957 059, raj.jagadeesan@daf.qld.gov.au

# Sulfuryl fluoride can break phosphine resistance

**Using an alternate fumigation chemical to break the development of insect pest resistance will help protect the efficacy of phosphine fumigation**

**By** Chris Warrick

## KEY POINTS

- Rotating phosphine fumigation with sulfuryl fluoride will protect against the development of phosphine resistance
- Sulfuryl fluoride can only be purchased and applied by licensed fumigators

■ Rotation with sulfuryl fluoride fumigation (ProFume® or Zythor®) is a viable option to prevent the development of phosphine resistance.

Sulfuryl fluoride carries no market restrictions when used correctly on cereal grains but is not registered for use on pulses or oilseeds.

## CHEMICAL OPTIONS

Phosphine is widely used in Australia as it is the only chemical fumigant that can be applied by growers without a fumigation licence. It should enable reliable control of storage pests when used properly in gas-tight storage, even for most pests with strong resistance. But not every fumigation is perfect; parts of the grain bulk might not have reached a high-enough gas concentration for a long-enough period to control all life cycle stages.

If any grain storage pests survive a phosphine fumigation, repeat fumigations with the same chemical will breed resistance very quickly.

There is also a strain of the flat grain beetle – specifically, the rusty grain beetle – which has very high resistance to phosphine. If flat grain beetles are found to have survived a fumigation with phosphine, a sample should be sent for testing and the grain bulk-fumigated with sulfuryl fluoride.

Unlike phosphine, sulfuryl fluoride can only be purchased and used by licensed fumigators. The fumigant itself is not expensive, but cost-effectiveness will depend on how far the licensed fumigator has to travel and how much grain has to be fumigated.

Monitoring grain regularly and well before planned outloading provides time to control insect pests and avoids costly, ineffective and often dangerous last-minute fumigation attempts.

## CONTROL TAKES TIME

All fumigants, including sulfuryl fluoride, require gas-tight sealable storage to effectively control insects at all life stages. Unsealed storages will not hold a high-enough gas concentration for a long-enough period of time to kill the eggs, larvae and pupae.

Research by the Queensland Department of Agriculture and Fisheries, with GRDC investment, has shown that effective control of all insect life stages with sulfuryl fluoride requires seven-day exposure for grain above 25°C, and 10-day exposure for grain between 20°C and 25°C. When grain is below 20°C, fumigation with sulfuryl fluoride is unlikely to be successful as the insect life cycle is too slow, meaning the gas is not absorbed by the adolescents.

If a shorter than seven-day fumigation is suggested, be aware that eggs, larvae and pupae will survive the fumigation and continue breeding.

Sulfuryl fluoride is a heavy gas at 3.7 times the density of the atmosphere. Most applicators will introduce the gas into the top of a storage, anticipating it will settle to the bottom. Best practice is to have some form of sealed recirculation system to gently transfer gas through the storage to ensure an even concentration throughout the grain bulk for the duration of the fumigation.

Without recirculation, it will take longer for the gas to reach all parts of the storage and, as it sinks, it will likely leave the top of the storage with a sub-lethal gas concentration.

Licensed fumigators are required to supply a clearance certificate once gas concentration is measured below three parts per million. Research and experience suggest this does not take very long and is typically achieved in less time than it would take to vent phosphine. For insurance, growers should insist on and keep a copy of the fumigation documents, including the clearance certificate. After venting, the label directs a one-day withholding period. □

**GRDC Code PRB2011-001SAX**

**More information:** Chris Warrick, 1800 WEEVIL, info@storedgrain.com.au; ProFume®, trical.com.au; Zythor®, ensystex.com.au

Photo: Chris Warrick


**Sulfuryl fluoride should be used in rotation with phosphine to prevent the development of resistance. Gas-tight sealable storage is required to control all life stages of grain storage pests.**

FOR INSURANCE, GROWERS SHOULD INSIST ON AND KEEP A COPY OF THE FUMIGATION DOCUMENTS, INCLUDING THE CLEARANCE CERTIFICATE.

# Phosphine curbs cowpea weevils in stored pulses

## A new study sheds light on the efficacy of phosphine control of cowpea weevil, or bruchids, in mungbeans and chickpeas

**By** Dr Greg Daglish, Dr Manoj Nayak, Dr Raj Jagadeesan and Phillip Burrill

### KEY POINTS

- Cowpea weevils – or bruchids – are an important insect pest in stored pulse crops in tropical and subtropical Australia
- They can be effectively controlled using label rates of phosphine fumigant in sealed silos over a minimum period of seven days
- No major differences in tolerance to phosphine were identified in 15 populations collected from multiple Queensland locations

Insect cages containing cowpea weevil (also known as bruchids) of all life stages were fumigated in silo-scale trials of mungbeans (pictured) and chickpeas to confirm the efficacy of standard label rates of phosphine against these pests.

Photo: Dr Raj Jagadeesan

■ There is growing demand for high-quality, insect-free Australian pulses such as mungbeans and chickpeas in the Indian subcontinent and Middle East. To meet the required quality standards and protect trade opportunities, it is critical for growers to protect harvested pulses from insect attack during storage.

While much is known about controlling pests that are typically associated with stored cereals, less is known about pulse-specific insects such as the cowpea weevil (*Callosobruchus maculatus*). These insects, commonly known as bruchids, can damage a wide range of stored pulses in the tropics and subtropics.

Phosphine fumigation is the only chemical treatment registered for pulses and has the advantage of being accepted by markets as a residue-free treatment. Although recommendations for fumigating cereal pests are based on extensive laboratory and field research, research on pests specific to pulses is limited.

The Queensland Department of Agriculture and Fisheries (DAF) recently investigated the effectiveness of phosphine fumigation of cowpea weevil. This research addressed key questions relating to the relative susceptibility of different life stages, treatment regimes and potential resistance in local populations.

### HOW MUCH IS ENOUGH?

DAF investigated two critical factors affecting fumigant efficacy against insects – time and concentration – in the laboratory using infested mungbeans and chickpeas. In other stored grain beetles, susceptibility varies across the different life stages, with eggs and pupae tending to be more tolerant than adults or larvae. For this reason, cowpea weevil infestations containing all life stages (eggs, larvae, pupae and adults) were used.

The research found that adults were very susceptible to phosphine, so researchers focused on suppression of adult progeny – or immature progeny that survived to adulthood – relative to untreated infestations. As expected, results showed that longer fumigation times and higher phosphine concentrations increase phosphine efficacy. But, importantly, the results showed that a seven-day fumigation at 360 to 720 parts per million (ppm) caused high levels of progeny suppression (99.7 to 100 per cent) in the test strains used (Table 1).

Development of resistance to phosphine is an ever-present threat, with resistance detected in all major cereal pests in Australia. DAF researchers evaluated 15 cowpea weevil populations collected from storage facilities in southern, central and northern Queensland for tolerance to phosphine. When mungbeans infested with all cowpea weevil life stages were fumigated for seven days at 360ppm, very little variation in phosphine tolerance was found. While this is reassuring and suggests a lack of resistance, more populations need to be tested to provide certainty.

## SILO FUMIGATION TRIALS

To confirm the efficacy of standard label rates of phosphine in the real world, researchers conducted silo-scale fumigation trials of mungbeans and chickpeas at the Hermitage Research Facility at Warwick in southern Queensland. Growers usually use aluminium phosphide tablets that react with moisture in the air, releasing phosphine gas over several days. The application rate for pulses stored at 25°C or higher is 1.5 tablets per cubic metre of silo capacity and the fumigation period is seven days.

Using these rates, mungbeans (in March 2019) and chickpeas (in March 2021) were fumigated in a nine-tonne sealable silo following the registered label for tablet formulations.

Cages containing cowpea weevil populations of all life stages were placed in various parts of the grain bulk, and phosphine concentrations were measured regularly at various locations in the silo. Fumigation efficacy was based on the number of adults that emerged in the laboratory from cages taken from the fumigated silo compared with cages from an unfumigated silo.

Phosphine fumigation in the silo was very effective in both the mungbean and chickpea fumigations, with a 99 to 100 per cent reduction in the number of adults emerging from the fumigated cages relative to the untreated cages. Phosphine concentration varied over time, as shown by the results for the chickpea fumigation (Figure 1), but far exceeded the concentrations that were effective in the laboratory fumigations (360 to 720ppm) for the majority of the time.

A pattern of increase and then decline in phosphine concentration was observed in both the mungbean and chickpea silo trials, which matched the typical pattern that occurs when cereals are fumigated with phosphine. Phosphine release from tablets can take several days, and phosphine is lost progressively during the fumigation through sorption by the grain and leakage. Even well-sealed silos leak, especially through the oil-filled pressure relief valve.

This research demonstrates that cowpea weevil can be effectively controlled using standard rates of phosphine and highlights the need for growers to fumigate pulses in a well-sealed silo over at least seven days to maximise exposure of all the insect life stages to phosphine. □

**Table 1: Effects of concentration and time on phosphine efficacy against cowpea weevil infestations in the laboratory (25°C).**

The pulses were infested with all life stages (eggs, larvae, pupae and adults). All adults died and less than 100 per cent suppression of progeny represents survival of immatures (eggs, larvae or pupae) to adulthood.

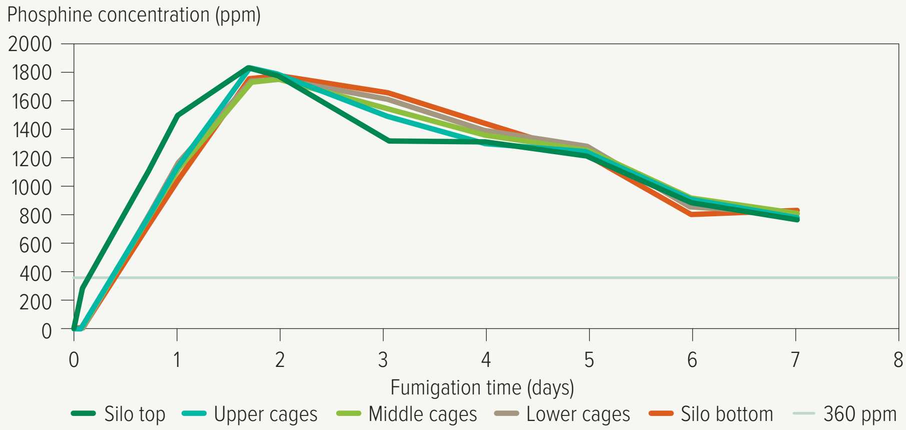
| Pulse | Phosphine (ppm) | Suppression of progeny (per cent) | | |
|---|---|---|---|---|
| | | 1 day | 4 days | 7 days |
| Mungbeans | 360 | 54.7 | 90.0 | 99.8 |
| | 720 | 69.0 | 99.8 | 99.7 |
| Chickpeas (kabuli) | 360 | 87.8 | 85.5 | 100 |
| | 720 | 98.1 | 99.8 | 100 |
| Chickpeas (desi) | 360 | 96.8 | 100 | 100 |
| | 720 | 100 | 97.1 | 100 |

Source: Dr Greg Daglish

Photo: QDAF

Cowpea weevil (also known as bruchids) is a damaging pest of a wide range of stored pulses, such as mungbeans (pictured) and chickpeas, in the tropics and subtropics.

**Figure 1: Phosphine concentrations measured inside a nine-tonne silo containing chickpeas fumigated in March 2021 show that fumigation for cowpea weevil was very effective. At the current label rate of 1.5 tablets per cubic metre of silo volume, phosphine concentration far exceeded 360ppm for most of the time.**




Source: Dr Greg Daglish

**More information:** Greg Daglish, 0481 905 650, greg.daglish@daf.qld.gov.au
GCTV Stored Grain: Storing Pulses youtu.be/CeWA-OdhhSk

# Lentil storage and the colour of money

### Lentil storage study to bring cold, hard facts to hot issue of safeguarding grain quality

**By** Dr Cassandra Walker, Dr James Nuttall, Ashley Wallace, Bhawana Bhattarai and Associate Professor Glenn Fitzgerald

Storing lentils on-farm can help growers streamline logistics and target better prices. However, the impact of storage on important market traits such as colour, cooking quality and germination is still a bit of a mystery.

Hot and sometimes wet summers mean grain can often exceed storage recommendations. Pulses should not exceed 25°C or 12 per cent moisture. But what happens to quality when high-value grains, such as lentils, are stored under these conditions and how long before it is detrimental to market targets?

A new study is quantifying these impacts, with GRDC and Agriculture Victoria co-investment through the Victorian Grains Innovation Partnership.

The work, undertaken as part of a PhD study through the Centre for Agricultural Innovation (a joint initiative between Agriculture Victoria and the University of Melbourne), aims to develop grain storage models to predict the quality of lentils stored in large-scale silos. These will enable growers to predict the ramifications of suboptimal conditions on lentil quality and clarify intervention steps to limit the impact.

Samples of four commercial red lentils – PBA Hurricane XT$^{\phi}$, PBA Hallmark XT$^{\phi}$, PBA Bolt$^{\phi}$ and PBA Jumbo2$^{\phi}$ – were collected from growers in the Victorian Wimmera after the 2020-21 harvest. The samples were placed in storage at four different temperatures (4°C, 15°C, 25°C and 35°C) and two different grain moisture conditions (10 and 14 per cent), which were sampled for analysis each month for 12 months. The quality traits being assessed in the study include:

- physical traits – seed coat colour, germination efficiency, splitting efficiency and cooking quality measured as hydration efficiency, grain hardness and cooking time; and
- chemical composition – total phenolics, total tannins and free fatty acids.

## IMPACT ON QUALITY

International markets place a high value on a bright red seed coat; however, lentil seed typically darkens during storage. The study, which measured seed colour using the Commission Internationale de l'Eclairage (CIE) colour parameters for brightness (CIE *L**) and redness (CIE *a**), found that all lentil varieties were significantly darker and browner after only two months when stored at high temperatures (25°C and 35°C) and that colour continued to decline at four months (Figure 1).

Initial grain viability was more than 97 per cent but, when stored at high temperature (35°C) and high moisture (14 per cent) for four months, germination efficiency dropped for PBA Bolt$^{\phi}$ (73 per cent), PBA Hallmark XT$^{\phi}$ (57 per cent) and PBA Hurricane XT$^{\phi}$ (84 per cent). Curiously, it remained unchanged for PBA Jumbo2$^{\phi}$. The other temperature and moisture combinations had no impact on germination after four months.

The study also found a significant decline in cooking quality, although not for all varieties. For example, three lentil varieties stored for four months at 35°C and low moisture (10 per cent) required more time to cook through, while PBA Hallmark XT$^{\phi}$ at the high temperature retained cooking quality after storage.

At high moisture all varieties needed more time to cook through when the grain was stored at high temperatures (25°C and 35°C). Seed that requires more time and energy to cook is particularly undesirable in countries where the cost of cooking fuel is expensive. □

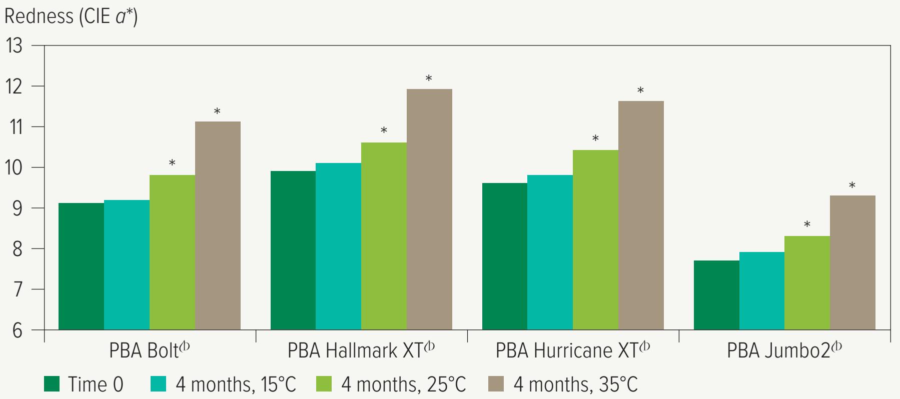
**GRDC Code DJP1910-006BLX**

**More information:** Dr Cassandra Walker, 0419 514 253, cassandra.walker@agriculture.vic.gov.au

Photo: Dr Linda McDonald

Agriculture Victoria's Dr Cassandra Walker and University of Melbourne PhD student Bhawana Bhattarai are investigating the impact of suboptimal storage on lentil grain quality.

**Figure 1: Lentil seed coat colour change over a four-month period was significant (*) when the grain was stored at high temperatures (25°C and 35°C). Colour measured as redness (CIE *a**) where increasing values represent deterioration.**




* P<0.05, LSD = 0.2 (time series x temperature x variety)

Source: Bhawana Bhattarai

# How good are stored grain protectants?

**By** Dr Manoj Nayak, Dr Jo Holloway, Dr Greg Daglish and Dr Raj Jagadeesan

■ Up to 30 per cent of freshly harvested grain is treated with contact insecticides – or grain protectants – before being placed into storage.

In the 1990s the development of multiple resistances to protectants in key pests, such as the lesser grain borer and red flour beetle, saw the introduction of binary applications.

Today, a triple combination of spinosad, chlorpyrifos-methyl and s-methoprene is used to control the entire spectrum of pest species that have developed resistance to one or two of these treatments. However, individual grain protectants are still used where multiple resistances are not present.

To help growers select effective protectants, the status of resistance to grain protectants in major pest species has been updated as part of an ongoing national GRDC investment in resistance monitoring for insect pests of stored grain.

The study, undertaken by researchers from the Queensland Department of Agriculture and Fisheries and NSW Department of Primary Industries, has reaffirmed the value of using combined treatments to overcome multiple resistances in key pest species.

The results also highlighted that some of the individual treatments are still effective in managing some species.

Field populations of four major pest species were collected from farm storages in Queensland, NSW and Victoria and tested for resistance. The 12 populations each of lesser grain borer and red flour beetle, 10 populations of rice weevil and five populations of saw-toothed grain beetle were tested in wheat treated with the protectants listed in Table 1.

Note that s-methoprene alone or in combination with spinosad is not registered for the control of rice weevil as a standalone treatment.

## RESULTS

The reduction in number of adult progeny was the main criterion for success, but adult mortality was also measured.

The triple combination was 100 per cent effective in progeny suppression against all four species tested. Lesser grain borer has developed resistance to several grain protectants in the past and needs to be watched carefully; however, results to date show that spinosad is highly effective against this species and resistance is less likely to develop.

The binary treatment of s-methoprene and spinosad delivered complete suppression of progenies in all populations, except for rice weevil. This combination is not registered for standalone control of rice weevil. In adults it only controlled lesser grain borer, most likely due to the spinosad.

Chlorpyrifos-methyl alone was ineffective against lesser grain borer, reflecting its long-standing resistance to organophosphate protectants. It successfully prevented progeny production in all other species but had poor control of saw-toothed grain beetle adults.

The growth regulator, s-methoprene, was ineffective against adults of all species tested, as expected. Resistance has been known to occur in lesser grain borer for many years and s-methoprene is not registered for standalone control of rice weevil. It achieved complete suppression of progenies in all populations of saw-toothed grain beetle and five of the 12 populations of red flour beetle.

Growers should continue to monitor for live insects in treated grain and, if detected, send to the nearest research laboratory for resistance testing or contact an expert via 1800 WEEVIL. □

**GRDC Code DAQ1906-002RTX**

**More information:** Dr Manoj Nayak, 0421 225 906, manoj.nayak@daf.qld.gov.au

Protectants 2021 youtu.be/tmRkwGj79ug

**Table 1: Number of field populations with 100 per cent adult mortality or progeny reduction in wheat treated with currently registered grain protectants: chlorpyrifos-methyl (chlor-ml), s-methoprene (s-meth), and spinosad (spin).**

| Species | State | Total number of field populations tested | Number of field populations with 100% adult mortality – Treatment (ppm) | | | | Number of field populations with 100% progeny reduction – Treatment (ppm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Chlor-ml (10) | S-meth (0.6) | Spin (1) + S-meth (1) | Spin (1) + S-meth (1) + Chlor-ml (10) | Chlor-ml (10) | S-meth (0.6) | Spin (1) + S-meth (1) | Spin (1) + S-meth (1) + Chlor-ml (10) |
| Lesser grain borer | QLD | 7 | 0 | 0 | 7 | 7 | 0 | 0 | 7 | 7 |
| | NSW | 5 | 0 | 0 | 5 | 5 | 0 | 0 | 5 | 5 |
| Red flour beetle | QLD | 7 | 7 | 0 | 0 | 7 | 7 | 3 | 7 | 7 |
| | NSW | 5 | 5 | 0 | 0 | 5 | 5 | 2 | 5 | 5 |
| Rice weevil* | QLD | 5 | 5 | 0 | 2 | 5 | 5 | 0 | 0 | 5 |
| | Victoria | 5 | 5 | 0 | 3 | 5 | 5 | 0 | 3 | 5 |
| Saw-toothed grain beetle | QLD | 5 | 0 | 0 | 0 | 1 | 5 | 5 | 5 | 5 |

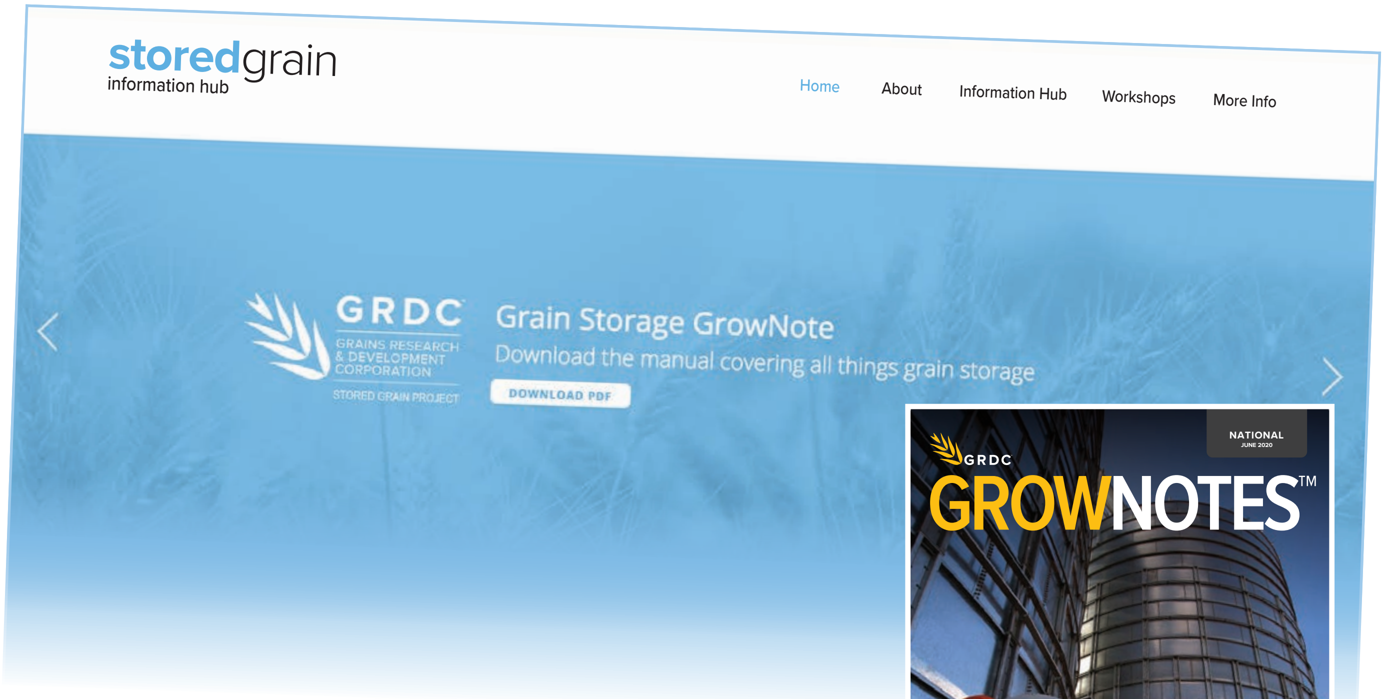
* s-methoprene alone or in combination with spinosad is not registered for the control of rice weevil as a standalone treatment.

All populations controlled | Some populations controlled | No populations controlled

Source: Dr Manoj Nayak

# Get the latest stored grain information online

## storedgrain.com.au





## The complete manual for on-farm grain storage

Call the National Grain Storage Information Hotline **1800 WEEVIL** (1800 933 845) to speak to your local grain storage specialist for advice or to arrange a workshop.

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION
STORED GRAIN PROJECT

**www.grdc.com.au | www.storedgrain.com.au | 02 6166 4500**