GRAINS: THE CHALLENGE

Civilisation was founded on the ability to harvest, store and distribute grain. Grain is harvested at specific times of the year and must be stored. The largest natural threat to the safe storage of grains is damage by insect pests. This threat is greatest in warmer climates, such as Australia, resulting in high infestation pressure and the potential for significant losses of stored grains.

Australia produces around 40 million tonnes of grain annually, worth $9 billion gross value to the nation. We are a key supplier of grains to our neighbours in Asia, the Pacific and the Middle East, exporting about 65% of our production.

Australia’s competitive position depends on its reputation as a reliable supplier of quality grain, free of insect infestation and with very low or zero chemical residues. Any perception that our export grain might be infested has a rapid and negative impact on our export trade position.

The unrelenting challenge for the industry is to ensure that our grain harvest is protected from insect infestation during storage. This must be achieved while maintaining high standards of quality, minimising or eliminating chemical residues and using treatments that are cost-effective.

The Australian grain industry relies primarily on fumigation of stored grain using phosphine. Phosphine is low cost (5-50 cents per tonne of grain), easy to apply, leaves little or no residues, is multi-commodity and accepted by international markets. However, the heavy reliance on phosphine is leading to development of resistance in all major target insect pests. Experience overseas indicates that resistance to phosphine will increase in frequency and strength over time.

*“Phosphine is unique, it underpins insect control in post-harvest grains for Australia. Unfortunately, over-reliance on this compound has inevitably led to resistance, this is one of the main threats to Australian grain food security and maintaining market access. Phosphine users need to adopt best practice to maintain this irreplaceable compound for the long haul. Accordingly the National Working Party on Grain Protection, strongly informed by PBCRC research, has developed the Strategy to Manage Resistance to Grain Protection Chemicals in the Australian Grain Industry.”*

Gerard McMullen  
Chair, National Working Party on Grain Protection

OUR WORK

With industry partners identifying resistance to phosphine as the most urgent issue, the CRC collaborated with the grains industry to develop a multi-disciplinary research portfolio to deliver practical solutions. Research was also initiated to support long term, sustainable grain biosecurity to underpin market access.

The objectives were:

- to effectively manage resistance to phosphine, including development of a national resistance management strategy
- to extend the working life of phosphine
- to develop cost-effective alternatives to phosphine, both chemical and non-chemical
- to provide essential knowledge of the biology of target insects to underpin long-term biosecurity.

A key feature of PBCRC’s approach was the participation of industry end-users in every project. The input of these end-users ensured any solution, whether short or long term, was cost effective and compliant with market expectations and regulatory requirements.

The impact

In 2017 the Plant Biosecurity CRC commissioned an independent assessment of the benefit to cost ratio of its research, this assessment was undertaken by The Centre for International Economics (CIE). The assessment concludes that for every $1.00 invested by the CRC in grains research, there is a $7.40 benefit, over a 30 year timeframe.

This benefit is based on a range of assumptions – these are fully detailed in The CIE final report. This high return is largely driven by the potential from the new silica technology package. In a sense, the package represents a ‘step change’ in fumigation, in contrast to steady incremental improvements that is characteristic of much research.


1. https://goo.gl/7De8W
RESEARCH IMPACT

Managing resistance

One of the first initiatives was to develop and deploy a nationally coordinated resistance monitoring program. Surveys undertaken by the Plant Biosecurity CRC have provided a better understanding of the frequency, distribution and strength of resistance to phosphine. The findings of this work showed that strong resistance development is being successfully contained. The most severe resistance incidences were caused by rusty grain beetle in eastern Australia, however, control failures due to these insects were halved due to the application of CRC-researched management tactics. The PBCRC funded monitoring program demonstrated its value by providing early warning of resistance developments, for example, effective action was taken in Western Australia to eradicate incidences of strong resistance detected there.

The CRC supported an extensive analysis of the Australian Grain Insect Resistance Database (AGRID) which is the repository of the many thousands of records associated with the national resistance surveillance program, collected over many years. The analysis provided new insights which identified that certain industry practices and storage types were associated with the development of resistance to phosphine.

Plant Biosecurity CRC research took an integrated approach to finding industry options for managing phosphine resistance. This work led to the development of highly successful phosphine application protocols for the control of outbreaks of resistance in rusty grain beetle. New protocols for the industry for the use of a newly registered fumigant which will help to reduce selection pressure on phosphine were also developed. Using genetic data, operational protocols and mathematical modelling the CRC research was able to provide advice to industry on the best fumigation application strategies for minimising resistance development. The operational protocols developed by PBCRC projects and knowledge gained about the process of resistance development, as well as industry experience, have all been incorporated into the national Strategy to Manage Resistance to Grain Protection Chemicals. This document was developed by CRC researchers in collaboration with industry and is endorsed by the National Working Party on Grain Protection.

More effective identification of phosphine resistance was also an outcome of CRC research. A molecular diagnostic was developed that detects and characterises phosphine resistance genes in pest insects. This assay can replace the limited and lengthy conventional bioassay method that is currently used. The test easily detects hidden resistance in insect populations. Identification of resistance genes and their function has also opened up the possibility of identifying alternative fumigants, synergists and new ways of using chemical treatments against resistant insects. Several options are under development as a result of this work. The importance of these findings is demonstrated by acceptance of this research for publication by the highly prestigious academic journal *Science*.

More successful, efficient and effective management of insect pest resistance leads to lower costs to the industry.

Extending the working life of phosphine

A number of CRC projects provided a range of industry-based protocols and methodologies to understand the fumigation process and improve fumigation treatments. These included investigation of the materials and methods most appropriate to maintain storage integrity and ensure effective control of insect pests. Outputs included a range of industry-ready procedures and manuals for implementing effective grain biosecurity. A strong example of industry adoption is the recommendations from this work being adopted in the construction of a large central grain storage in Western Australia. Procedures were also developed for safe ground level application of phosphine on-farm and for the use of phosphine generators and thermosiphon technology.

In a collaborative project led by industry partners, Plant Biosecurity CRC research mapped the flow of phosphine gas inside storages and through bulk grain and the effect on gas movement of external factors such as temperature and wind direction and strength. This information was then used to develop predictive models of gas flow, results of which have helped to improve application and storage design.

Given the surge in installation of large grain storages on farm, the CRC supported an initiative to provide data to support an extensive up-dating of the phosphine registration label. This is a complex process that requires the cooperation of industry, business, government and researchers.

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http://www.graintrade.org.au/nwpgp

**Overall, the CRC’s research into resistance monitoring is expected to result in reduced costs of resistance to the industry worth of $21.5 million. This represents a return of $2.48 for every dollar invested by the Plant Biosecurity CRC in resistance monitoring research.** *(The CIE p. 102)*
Cost-effective alternatives, chemical and non-chemical

The Plant Biosecurity CRC has made exciting progress in the identification of alternatives to phosphine. This includes successfully developing a clean, non-chemical technology for disinfesting and safely storing cereal grains and oilseeds. The technology uses nitrogen to exclude oxygen from the storage and its commercial viability was demonstrated in a series of trials undertaken on the property of a farmer participant in the project. The technology has also been installed at a grain port in Western Australia.

A promising non-chemical technology package, developed by the CRC, applies silica to protect grain and storage surfaces. Laboratory experiments and field trials have demonstrated the extraordinary efficacy of this material and technology, and the CRC has invested in its further development and commercialisation.

The use of silica represents a potential 'step change' in fumigation practice. PBCRC research has indicated it is potentially cost-effective, and, as it is not a harmful chemical, it may also allow premiums for a chemical-free product in the export market.

CRC collaborators based at Kansas State University have also investigated the potential of ozone and chlorine dioxide as fumigants. They found that these materials effectively controlled phosphine resistant insects. Research to adapt them for application to the stored grain environment is continuing.

A different treatment approach explored was to reduce the temperature of grain by introducing cool dry air into the silo (aeration). This technology is particularly important and useful for farmers to improve temperature and moisture control in grain storages, considerably reducing pest populations and their impacts on stored grains. However, until now, there was no way for farmers to measure whether the air flow within their silos was sufficient for the purpose. Plant Biosecurity CRC researchers developed a practical methodology to measure air flow rates that farmers can use themselves to greatly improve the efficacy of this treatment.

To maximise the industry exposure and opportunity for industry members to test and view demonstrations of alternative treatments, the CRC established a series of industry ‘impact sites’ across WA, NSW, SA and Qld to trial these options. These impact sites allowed for a unification of key findings of CRCNPB/PBCRC grain-based investments under the structure of documenting best practice. PBCRC supported a range of industry workshops and demonstration activities for grain producers at the impact sites, which have resulted in many producers modifying their on farm storage systems.

Essential knowledge of the ecology of target insects to underpin resistance management and long term biosecurity

The Plant Biosecurity CRC supported ground-breaking research that developed new understanding about the movement of insects in the landscape and quantified gene flow and colonisation in relation to resistance development. The research revealed for the first time that these insects disperse through flight broadly in the landscape, overturning the accepted international view that they are redistributated primarily through the movement of infested grain from one storage facility to another.

Flight dispersal was also found to continue for many months of the year and molecular studies showed, that as a consequence, there was a high level of genetic and demographic connectedness across the landscape. Differences in walking or flight initiation behaviour between resistant and susceptible insects was also demonstrated to be minimal which indicated that resistance genes are dispersed broadly from the point of selection as readily as wild type genes.

Extensive insect trapping studies revealed that different insect pest species show quite distinct flight activity and distribution in relation to grain storages and other features of the landscape. These results have overturned assumptions regarding the dispersal of these insects and have led to new options which could be explored for pest management.

A spin-off from these ecological studies was the development and commercialisation of a lure for the rusty grain beetle (Cryptolure™), which industry can use to facilitate management of this pest.

“The CRC has made a significant difference to the Australian grain industry in providing world class research that supports Australia’s reputation as a reliable supplier of quality grain to the world. This research has provided end-users with the ability to modify internal processes to maintain phosphine use, as the key fumigant used in the industry and controlling/preventing insect resistance to phosphine.”

Greg Hopkins
Grain Hygiene Manager, Viterra Ltd

An independent assessment of the benefit to cost ratio of the successful development and application of this silica based fumigation approach is 10.5:1. That is for every $1.00 invested in the research by the CRC there is a $10.50 benefit (The CIE p. 111).
CAPACITY BUILDING

In 2008 PBCRC’s predecessor the CRC for National Plant Biosecurity supported the development of a Principal Scientist position at Western Australia's then Department of Agriculture and Food (DAFWA) with secondment arrangements to Murdoch University. The focus of this position was in providing leadership in stored grain research and supporting grain storage and exports from western grain zones.

Professor Yong Lin Ren, a world leader in post-harvest plant biosecurity, was recruited to this position due to his expertise and commitment. The position, based at Murdoch University, has proved successful on a number of levels. For example Professor Ren has played a key role in the development and training of the next generation of grain biosecurity researchers, supervising 13 postgraduate students. Another important achievement has been the signing of three new collaborative agreements with Chinese government research and policy agencies. The new agreements bring together leading researchers from both countries and represent a significant step in collectively developing key technologies to enhance grain storage efficiency and safeguard trade.

PBCRC concluded financial support for the position in mid-2015. In recognition of the importance of the laboratory and the Principal Scientist position, Western Australia’s Department of Primary Industries and Regional Development now provides ongoing support for the role.

Capacity has also been enhanced in postharvest grains with the establishment of a postharvest biosecurity and food safety research laboratory in WA. This is the west’s first research and development facility dedicated to stored grain and complements the research capacity along the east coast.

The laboratory and research has been critical in developing and deploying key PBCRC research such as nitrogen/low oxygen technology for the control of grain pests in storage.

"The laboratory has been an important achievement for the grains industry. We’re very focussed on managing postharvest grain risks and the work of Professor Ren and his team is important to ongoing industry efforts to safeguard trade."

Ern Kostas
Grain Protection Manager, CBH Group Ltd

IMPACT CASE STUDY

Phosphine resistance monitoring

The heavy dependence of the grain industry in Australia on phosphine, coupled with their previous experience of loss of chemical insecticides because of resistance, motivated our industry partners to request the Plant Biosecurity CRC to develop a national resistance monitoring program. The primary role of the program was to provide early warning of incipient resistance problems, but it was quickly recognised that the data produced in monitoring surveys could be used by industry to diagnose the cause of control failures, to make tactical decisions about managing resistance and to provide a strategic overview of resistance frequencies across the grain industry.

Under CRC management the three state laboratories combined into one project. They successfully reviewed and harmonised their reporting procedures, sampling, testing and statistical methods, and reported their results on a central database. The program tested around 2500 insect samples from about 1000 farms each year and 400 insect samples from central storages. This information was presented annually to the grain industry at the Australian Grain Storage and Protection Conference and is stored in the AGIRD.

The monitoring program is a key component of Australia’s highly effective national resistance management strategy. Key successes include the early detection of strong resistance to phosphine in the rice weevil and mapping of the emergence of strong resistance in the rusty grain beetle. Early detection allows researchers time to evaluate the likely impact of new resistance and to develop protocols to manage it.

An important contribution has been the development of protocols, in collaboration with industry, to control the rusty grain beetle. In eastern Australia, the Program provided crucial information on new infestations of resistant rusty grain beetle and feedback on the success of management interventions.

The monitoring program also detected outbreaks of strong resistance in Western Australia, which were subsequently eliminated, maintaining that State’s freedom from strong resistance. These actions made use of the rapid diagnostic methods developed by the Program to inform timely decisions.

The CRC undertook a systematic analysis of the data stored in the AGIRD. This data-mining identified several scenarios and storage types associated with higher risk of resistance and has been used to prioritise research and extension investment.

"This program is fundamental in underpinning research on resistance management and is crucial in helping the industry to understand and deal with complex biosecurity issues such as high levels of resistance in Cryptolestes ferrugineus, its frequency and distribution and methods of control."

Phil Clamp
Quality Assurance Manager, GrainCorp Operations Limited

Ern Kostas
Grain Protection Manager, CBH Group Ltd
IMPACT CASE STUDY

Controlled atmosphere technology

The ‘controlled atmosphere’ or ‘low oxygen’ technique offers a completely chemical free treatment for disinfestation and protection of stored grain. Insect pests can be controlled by reducing oxygen to very low levels within a silo. The levels required are obtained by purging silos with an inert gas and sealing the silo to prevent ingress of oxygen.

Although sound in principle, there were major applied research challenges to implementation of this technique on an industrial scale. These included the need for a practical and relatively cheap source of inert gas, the application of the gas to storages, and the requirement for a system that maintains a very high concentration of the inert gas and prevents ingress of oxygen. There were also several basic research questions associated with understanding the toxic effect of low oxygen on target species and the reaction of living grain in such an atmosphere.

The most practical inert gas is nitrogen as it can be extracted directly from the atmosphere. Trials were initially undertaken on medium scale wheat storages to evaluate the cost-effectiveness and suitability of a nitrogen generator and gas application methods. At large farm storages in Lake Grace (WA) insect and chemical-free wheat was produced that was sold at a premium of $20-30 higher than conventionally treated wheat. The technology maintained both wheat and canola in excellent quality. However, the cost of this technology and the need for gas-tight storages remained barriers to wider adoption.

To address the issue of costs, the CRC partnered with the Changshun Anda Company to develop a more economical nitrogen generation (membrane) technology. The new generator has been installed at the grain port of Kwinana WA where it has performed well. The technology generated the required level of nitrogen purity within 4.5 days of operation and successfully maintained a low oxygen atmosphere for the required 14 days, providing full control of pests. Initial costings indicate that the nitrogen technology operated at just under $1 per tonne of grain. Researchers are working to make the technology cost-competitive with phosphine. The CRC has also developed a partnership with the Mingenew Irwin Group to adapt the new technology to benefit farmers.