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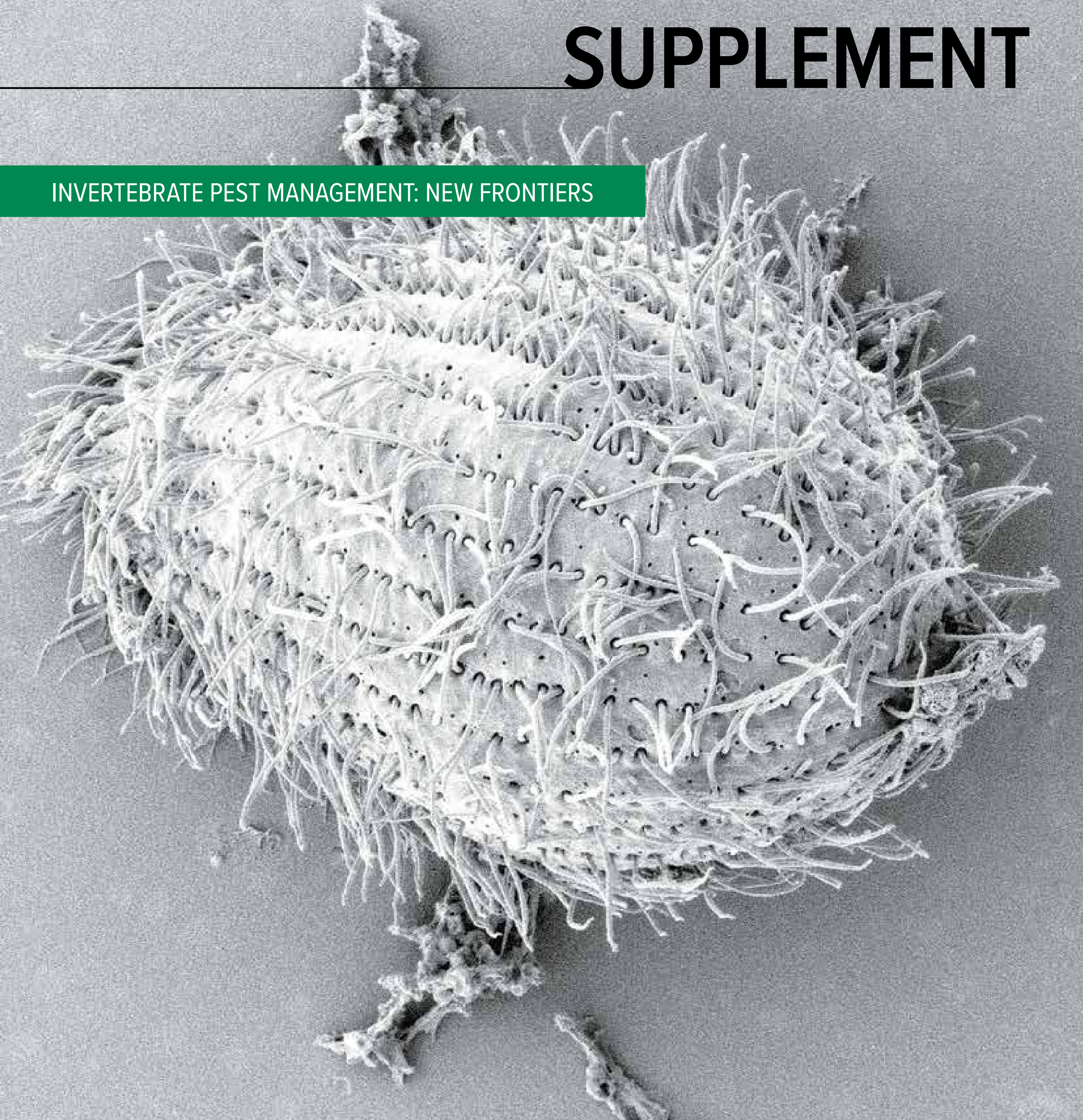
GRDC

GROUNDCOVER SUPPLEMENT

INVERTEBRATE PEST MANAGEMENT: NEW FRONTIERS



4 KNOWLEDGE GENERATION
Lateral thinking charts new territory

12 DRIVING CHANGE
Values underpin action on pests

18 NOVEL APPROACHES
Fortifying fungus tackles pests

TECHNOLOGY AND MINDSET CHANGES TO DRIVE NEW PEST MANAGEMENT ERA

Novel invertebrate pest management tools and techniques are set to become part of more holistic integrated pest management (IPM) programs as insecticide resistance and regulatory concerns increase

By Dr Leigh Nelson

■ Managing the ever-changing complex of invertebrate pests is an ongoing challenge for the Australian grains industry. Effective, efficient and sustainable pest management is vital for enduring, profitable farming systems. Although pesticides are one of the tools to achieve this, global regulatory pressures, market requirements and increasing insecticide resistance are driving the need for a paradigm shift in invertebrate pest management.

NEW FRONTIERS

New frontiers for integrated pest management (IPM) are being explored through GRDC investments that are digging deeper into understanding pests, their life cycles and their interactions with crops, the environment and beneficial insects. Researchers are thinking laterally to develop novel control measures and tools. Extension experts are investigating what drives growers' and advisers' decision-making to design support aids that will improve adoption of IPM.

A greater depth of understanding is required to pre-empt and reduce pest outbreaks, monitor changes in pest impact and abundance more effectively, and facilitate whole-farm systems approaches to pest management.

Monitoring and mapping the insecticide resistance of several in-crop invertebrate pests is underway using new technologies. These pests include the green peach aphid, cotton bollworm and redlegged earth mite. Baseline information and forecasting of these pests can inform best management practices for growers.

Further down the value chain, Australia must adhere to a strict 'nil tolerance' protocol for live insects in its export commodities to preserve market access. A critical part of this is a GRDC investment monitoring insecticide resistance in grain storages across the nation. Growing insecticide resistance, together with tightening regulatory concerns, will mean biologically based insect control methods will be increasingly required throughout the grain value chain.

KNOWLEDGE BANK

GRDC investments are developing knowledge about the ecology and biology of pests to inform dynamic decision-making tools. These will consider pest risks and incorporate forecasting information.
Resistance forecasting helps to prevent spray failures by enabling selection of effective pesticide chemistry. Investments are exploring novel controls to decrease disease transmission and pest feeding impact. Additional investments are improving chemical stewardship and exploring opportunities for harnessing the power of beneficial insects.

NOVEL APPROACHES

To broaden the suite of crop protection tools available, GRDC continues to invest in innovative approaches to pest management, including:

- testing a nature-identical synthetic molecule with a unique mode of action against stored grain pests;
- establishing an association between wheat and a grass-colonising fungi to provide host plant protection against pests, pathogens and abiotic stresses;
- using naturally occurring protozoa to control pest molluscs;
- using parasitoid wasps to control aphids; and
- optimising food-grade, synthetic amorphous silica technology for protecting stored grain.

While sometimes high-risk, GRDC investments in novel approaches ensure that the Australian grains industry is primed to seize opportunities to tackle intractable invertebrate pest issues.

GRDC will continue to chart new frontiers to develop more cost-effective and sustainable options for Australian grain growers to manage invertebrate pests, ensuring that the industry continues to be a global leader. □

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COVER IMAGE: Potential biocontrol agent for grey field slugs (*Deroceras reticulatum*) – a parasitic ciliate protozoa (*Tetrahymena rostrata*) at x5000 magnification under a scanning electron microscope.

PHOTO: Associate Professor Helen Billman-Jacobe

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New knowledge supports integrated pest management

By Dr Hazel Parry

KEY POINTS

- Integrated pest management (IPM) adoption needs boosting
- 'Knowledge cards' with ecological pest facts are available from GRDC
- Knowledge and forecasting of beneficial insects could be a key IPM tool

■ Integrated pest management (IPM) combines multiple strategies for managing insect pest outbreaks. These include detection and monitoring, effective and selective chemical use, and undertaking practices that avoid problems occurring in the first place.

To this end, GRDC invested in a five-year project with CSIRO – in partnership with **cesar**, the Western Australian Department of Primary Industries and Regional Development (DPIRD), New South Wales Department of Primary Industries (DPI), South Australian Research and Development Institute (SARDI) and the University of Melbourne – to identify the knowledge gaps that are holding back adoption of IPM, to address these gaps and to design novel, user-friendly resources.

Five key gaps were identified:

- What causes pest outbreaks?
- What factors affect abundance and intermittent pest status of transient pests (such as earwigs and millipedes)?
- How should we monitor for pests?
- What are the impacts of natural enemies on pest numbers in the field?
- Which species are important as pests or natural enemies?

WHEN, WHERE WILL THEY STRIKE?

Predicting when and where invertebrate pests will reach high densities and cause damage that results in yield loss in grain crops is a challenge. It is only by making many observations over time and at multiple locations that we can begin to understand the environmental factors that influence populations. Studying interactions between pests and the crop, or predation by beneficial insects, is difficult in the field, so we often use 'microcosm' or laboratory studies. Through these studies in both the field and microcosm, the project has generated knowledge on the life cycles, crop damage potential and distribution across the southern grain growing regions of Bryobia mites, slaters, millipedes and earwigs.

In the case of earwigs, we also identified that nearly all earwig species are omnivorous (herbivore pests that are sometimes predatory), with only common brown earwig (*Labidura truncata*) solely a beneficial predator. Our trials have shown that lucerne and canola seedlings are the most vulnerable to earwig damage. This information is now available through GRDC as a series of 'invertebrate knowledge cards', such as the example shown in Figure 1.

INTEGRATING CONTROL MEASURES

Effective IPM is not just about understanding what causes pest outbreaks; it is also about understanding the impacts of natural enemies that assist in controlling pests. The studies on parasitoid wasps by Samantha Ward for her GRDC-supported PhD studies have shown just how much these beneficial insects contribute in the fight against aphids, often without us knowing.

Field cage studies across multiple regions showed effective aphid pest suppression by beneficial insects, including lacewings, ladybird beetles and parasitoid wasps. It is therefore important that pesticide management regimes consider potential impacts on these allies. We are finalising further studies into the effects of neonicotinoids insecticides on beneficial insects.

IMPACTS OF BENEFICIAL INSECTS?

Laboratory studies on the consumption rate of aphids by ladybird beetles have allowed us to quantify the combined impacts of initial aphid density and temperature on the predicted number of aphids consumed.

This data, along with data from many other studies, has been used to inform the development of a computer simulation model. The model provides valuable insights into key drivers that affect aphid populations and their control by beneficial insects. It is an important step towards 'digital IPM' – decision tools that are fully integrated with automated monitoring and forecasting from such models.

A reinvigorated effort is required to boost IPM practices to ensure the sustainability and profitability of the Australian grains industry. This will be achieved by applying new knowledge about pests and their enemies that could be used to control the pests and by deploying digital IPM decision tools to assist in monitoring, forecasting and decision-making for smarter pest control. □

GRDC Code CSP1501-002 (CSE00059)

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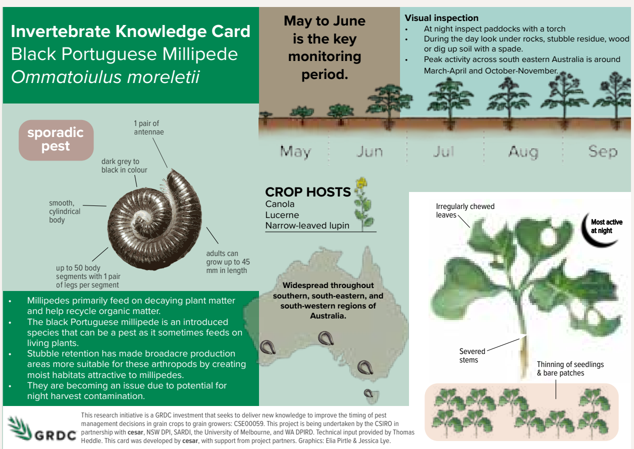

Figure 1: An example of an invertebrate knowledge card. This one explains the life cycle, crop damage potential and distribution of black Portuguese millepede (*Ommatoiulus moreletii*).

Photo: Dr Andrew Weeks, cesar

New approaches to invertebrate pest management

Research investigating insect pest management is focusing on delivering a range of novel control options for decreasing disease transmission and pest feeding impact

Understanding of the importance of beneficial insects needs to be bolstered. Ladybird beetles can play a significant role. Here, one is feeding on an aphid colony.

By Francesca Noakes

KEY POINTS

- Invertebrate pest management in grains is complex and adoption of integrated pest management approaches is slow, so innovative new approaches are being examined
- Selection pressure is a main driver of resistance evolution. Work is underway to better estimate such pressures for grains pests
- The potential for manipulating endosymbionts (bacteria that live in insects) is being explored to see if they can be used to disrupt insect pest survival

■ Emerging issues such as insecticide resistance in key pests, possible regulatory withdrawal of important chemicals in the future and a growing recognition of the role that beneficial insect species can play are motivating growers and researchers to seek novel solutions to the challenge of insect pest control.

The Australian Grains Pest Innovation Program (AGPIP) – a collaboration between the Pest & Environmental Adaptation Research Group at the University of Melbourne and **cesar**, with GRDC and University of Melbourne investment – is looking to apply out-of-the-box thinking to some of the grain industry's most troublesome pest management challenges.

In Australian grains, insect pests are responsible for more than $350 million in yield loss or damaged product per year. Insect damage to crops can occur directly through feeding damage or indirectly through the transmission of viruses. The cost of controlling pests involves labour, product purchase and application, monitoring and testing costs, and professional advice. It can represent a significant expense in a farm's yearly budget and issues such as insecticide resistance can further complicate pest management.

Led by Associate Professor Paul Umina and Professor Ary Hoffmann at the University of Melbourne, AGPIP is undertaking research and extension activities that support the transition to more sustainable and cost-effective pest management practices.

"We seek to shine a light on some of the remaining mysteries when it comes to control of insect pests," says Associate Professor Umina.

"This will support better-informed decisions about control of certain key pests as well as potentially offering new options for pest management.

"Sometimes you need to think laterally to achieve a step change in how we approach these issues."

DRIVERS OF RESISTANCE

Insecticide resistance is a growing issue for the grains industry, with common pests such as the green peach aphid (*Myzus persicae*), redlegged earth mite (*Halotydeus destructor*), diamondback moth (*Plutella xylostella*) and cotton bollworm (*Helicoverpa armigera*) having already evolved resistance to registered insecticide options.

The evolution of resistance in pest populations reduces the options available for managing potential outbreaks

Research is enhancing integrated pest management using endosymbionts, by exploring the use of bacteria that live in insects to see if they can disrupt the insect's life cycle. Green peach aphids (above) after micro-injection with *Buchnera* bacteria. The green morph has not been altered, the yellow morph has been injected with *Buchnera* (which alters its colour) and the little nymph is the offspring of the injected aphid line.

Photo: Dr Xinyue Gu, PEARG

and can increase selection pressures for remaining chemical actives.

While selection pressures (such as pesticide exposure) are a main driver of resistance evolution, the industry lacks reliable methods to estimate selection pressures for grains pests. Also, there is a variety of other factors that may accelerate or delay the evolution of resistance in an insect pest, including the local environment, species biology and ecology.

By improving estimates of selection pressures and increasing the understanding of other factors driving resistance, AGPIP research will support identification of resistance risks before the resistance evolves or becomes widespread. This research will help the industry to predict when, where and how resistance might occur, and help direct the development of resistance management strategies.

ENLISTING BENEFICIALS

The capacity for natural enemy species to contribute to pest management systems through their parasitism and predation is increasingly recognised. However, the incorporation of biological pest control practices into existing pest management strategies is constrained by knowledge gaps regarding the pest suppression capacity of natural enemy species in grain systems and the impact of pesticides on these species.

AGPIP is looking to fill these gaps and develop a guide for growers that details insecticide and miticide toxicity ratings for natural enemies of grain pests. This work will combine existing research, with additional laboratory testing to fill knowledge gaps of pesticide impacts on species. The research will seek to account for both the direct impacts (through mortality) and sublethal impacts (such as on reproductive capacities) of the pesticides tested. In the long-term, the research will help grain growers identify chemicals that are less disruptive to their natural enemy populations so as to better utilise this free biological service.

ENDOSYMBIONT RESEARCH

The most blue-sky research being undertaken through AGPIP is examining options to manipulate tiny microorganisms living inside pest insects (called endosymbionts) to reduce the risk of crop damage and plant virus transmission.

Endosymbionts are bacteria that live in the cells of other organisms (such as insects) in a symbiotic relationship. Co-evolving over thousands or millions of years, endosymbionts can become crucial to certain survival processes in the insect host. These processes may include nutrition, reproduction and resistance to external pressures such as insecticides. They may also impact on the insect's ability to transmit viruses and its susceptibility to predators.

By manipulating endosymbionts within the insect, it is possible to disrupt these processes and weaken pests. AGPIP researchers are looking to use this approach in pest aphids to reduce the impacts of direct feeding damage and aphid-to-plant virus transmission. This will be achieved through transfers of particular endosymbionts from one aphid species into another, as well as the suppression of endosymbionts in pest species through heat and chemical treatments.

Similar work is planned on endosymbionts in pest moth species and the beneficial species that attack the moths' larvae. This research aims to increase rates of parasitism and predation of the pests. Both the resistance of beneficial organisms to pesticides and their reproductive rates could be increased through endosymbionts, enhancing their efficiency in controlling pests. Led by Professor Hoffmann, the research team at the University of Melbourne has previously been successful in manipulating endosymbionts in mosquitoes to reduce transmission of Dengue virus.

"Taking the lessons learned from our work with mosquitoes, we hope to be able to replicate these successes in key insect pests and reduce the risk of crop damage for growers," Professor Hoffmann says.

The manipulation of endosymbionts offers a different and more sustainable option for managing agricultural insect pests in the future, in which the microorganisms in the pest become as much the target as the pest itself. ☐

GRDC Code UOM1906-002

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National resistance monitoring to direct pest control

Phosphine is the predominant grain fumigant due to its low cost and ease of application. But resistance to the fumigant is rising and its use needs to be carefully monitored

By Dr Manoj Nayak, Dr Greg Daglish, Dr Rajeswaran Jagadeesan, Dr Joanne Holloway and Dr Oonagh Byrne

CHECK LIST

- ✓ Ensure the highest standard of fumigation. Pressure test storages to ensure gas-tightness to meet recommended minimum concentrations and exposure periods. Invest in storage that meets the Australian Standard AS 2628, and seek advice from a local member of National Grain Storage Extension Team (phone 1800 WEEVIL).
- ✓ Limit the number of phosphine fumigations (two to three) for the same parcel of grain.
- ✓ Use alternatives such as sulfuryl fluoride only when strongly phosphine-resistant rusty grain beetles are detected. The existing label rates should control all other resistant pest species.
- ✓ Use grain protectants on freshly harvested grain. Treating old, infested grain with protectant chemicals will not control the infestation – only fumigation can disinfest it.
- ✓ Monitor insect infestations regularly. Send samples to a nominated regional laboratory for resistance testing and get further advice on pest and resistance management strategies.
- ✓ Adopt a proactive hygiene program. Clean up grain residues regularly in and around storages. Use diatomaceous earth in empty storage structures.
- ✓ Rotate grain treatments where possible. Use grain protectant products (such as chlorpyrifos-methyl and deltamethrin) and fumigants (such as phosphine and sulfuryl fluoride). This approach will break the resistance cycle for the respective treatment.

■ To maintain its position in highly competitive grain markets, Australia needs to adhere to a strict 'nil tolerance' protocol for live insects in its grain exports. To do this, the industry needs to minimise the development and spread of insecticide-resistant stored grain pest populations.

Preserving market competitiveness, and agricultural sustainability, can be achieved through best management practices. A critical part of this is a national insecticide resistance monitoring program.

NATIONAL RESISTANCE MONITORING

Since 1992, with GRDC investment, Australia has been the only country to have a national resistance monitoring program that systematically monitors and manages resistance to phosphine. Continuing this legacy, a GRDC-invested national program was initiated in 2019 to determine the frequency and strength of resistance to fumigants and grain protectants in major storage pests.

The national program runs collaboratively across the three GRDC regions (western, southern, northern) and is pivotal in limiting the frequency and spread of strong resistance to phosphine.

Led by the Queensland Department of Agriculture and Fisheries (QDAF), the three-year GRDC investment aims to survey 100 farms per year in each of these regions and undertake resistance diagnoses of several thousand pest populations over the life of the project. This will deliver a comprehensive assessment of resistance nationally, with implications for pest and resistance management options.

Laboratories will follow a statistically robust protocol to determine two levels of phosphine resistance (weak and strong). While monitoring weak resistance provides early indications towards future development of strong resistance, the results on strong resistance guide the implementation of appropriate management strategies to control those populations and contain their spread.

The scope of the most recent investment has expanded to include monitoring of another fumigant, sulfuryl fluoride, and some grain protectants (for example, spinosad and chlorpyrifos-methyl). It is timely that resistance to sulfuryl fluoride be monitored due to its ongoing use by growers since its adoption in 2009 as a 'phosphine-resistance breaker'. Grain protectants are used by about 20 per cent of growers in grain stored for a long period.

As part of the national program, a scoping study is being conducted in farm storages in the Townsville region to determine the pest spectrum and resistance gene frequencies. Townsville is traditionally a sugarcane region, but in recent years there has been a significant interest in cereals and pulses. In addition, Townsville is being positioned as a port of significance for containerised grain exports.

The aim is to explore the unknown factors related to phosphine resistance in this region bordering Charters Towers, Burdekin and Hinchinbrook, especially given the recent changes in cropping patterns and movement of grains across this and other regions, including central Queensland and the Darling Downs.

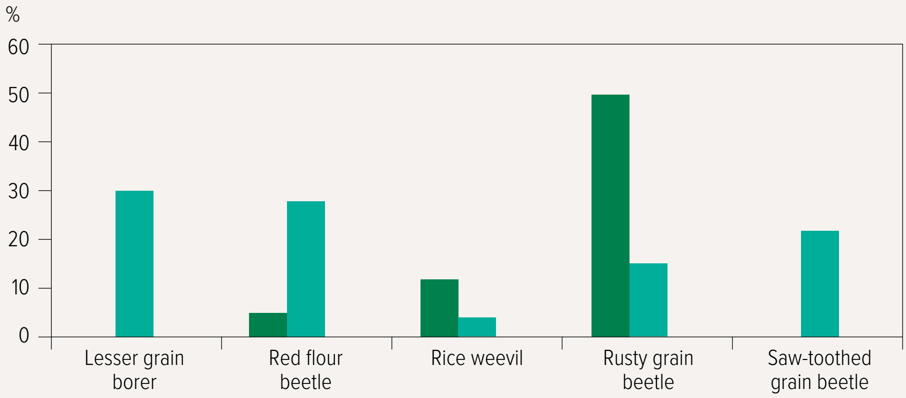
FINDINGS

In the first year of the project (2019-20), despite COVID-19 restrictions, 158 insect populations were collected from 70 farms in the southern region, 385 populations from 63 farms in the north and 162 populations from 38 farms in the western region. While several of these populations are still being tested, diagnosis has been completed for 36 southern populations, 202 northern populations and

Photo: QDAF

In the northern region, 30 per cent of lesser grain borers (*Rhyzopertha dominica*) tested showed strong insecticide resistance profiles.

Figure 1: Percentage of stored grain pest populations diagnosed with strong levels of phosphine resistance in farm storages across the three grain growing regions of Australia.



Source: QDAF

122 populations from the western region.

Overall, five (14 per cent) of the southern populations and 43 (21 per cent) of the northern populations were diagnosed as strongly phosphine resistant. Strong resistance was not detected in any of the 122 populations tested from the western region.

In summary, the northern region leads the strong resistance detections, with 30 per cent of the lesser grain borers, 28 per cent of the red flour beetles and 22 per cent of saw-toothed grain beetles tested revealing strong resistance profiles.

However, 50 per cent of the rusty grain beetles tested from the southern region were recorded as strongly resistant (Figure 1). All of the remaining populations from the northern and southern regions, and about half of those from the western region, were weakly resistant. Thus, the western region is the only region with populations susceptible to phosphine.

While resistance results are still pending for several populations, findings obtained so far show a trend in strong resistance frequency to be 14 per cent nationally. This elevation in frequency from the earlier five-year average of 10 per cent can be attributed to increased incidence of strong resistance in red flour beetles, lesser grain borers and rusty grain beetles, particularly in the northern and southern regions.

Recent visits to several farms have confirmed that residual pest populations do survive in empty storages during winter. If these pest populations are left untreated and/or storages not cleaned, they will infest new season grain when it is put into storage. Repeated fumigations to control these pests increases the likelihood of sublethal exposure and selection of resistance to phosphine.

There needs to be more awareness of how to best utilise lean periods such as winter to invest in hygiene in and around the storages.

NEW REGIONS NOT IMMUNE

Sampling of 14 storage sites (including farms, feedlots and grain processors) in the Townsville region, as part of the scoping study, revealed the incidence of at least one pest species population at each site. Further, all five major pest species were recorded in seven (50 per cent) of the storage sites inspected.

Molecular screening of lesser grain borers and red flour beetles revealed the presence of genetic variants linked to strong phosphine resistance in the populations of these species. Phosphine use to disinfest pests is limited in this region, so the prevalence of multiple resistant variants in pest populations suggests the possible movement of resistant insects via transportation of grain between Townsville, Central Queensland and the Darling Downs. This further highlights the importance of pest and resistance monitoring.

Emerging challenges for growers include the potential for more widespread occurrence of strongly resistant rusty grain beetles and rice weevils, particularly in the southern and northern regions.

The future direction in this research program includes development and inclusion of 'quick tests' for different stored grain pest species and undertaking molecular diagnostic monitoring of pest populations of other regions. □

MythBusters

Stored grain pests are not around the storages when they are empty.
WRONG – Recent sampling in empty storages across many farms revealed several pest species in good numbers.

There is no need to clean storages if insects are not visible.
WRONG – A hygiene program should be deployed to kill the residual insect populations that are hiding and waiting to feast on the freshly harvested grain.

Grain protectants can be used to disinfest insect infestations.
WRONG – Grain protectants should only be used on freshly harvested grain. Infested grain should be fumigated.

Pickled seed grain provides protection from insect infestations.
WRONG – Many pickled seeds have fungicides that do not provide protection from insects.

'I bought my silos and was told they are compliant to the Australian Standard (AS2628), so I don't need to worry about pressure testing'.
WRONG – Regular maintenance and pressure testing before each fumigation is required to ensure a silo can perform as an effective fumigation chamber.

GRDC Code DAQ1906-002

More information: Dr Manoj Nayak, manoj.nayak@daf.qld.gov.au

Pest detectives tracking the green peach aphid

Genetic profiling is the latest tactic against green peach aphid

By Francesca Noakes

KEY POINTS

- Green peach aphid (GPA) damages crops by direct feeding and as a virus carrier
- GPA is evolving resistance to many insecticides
- Through genetic profiling, an aphid clones database allows researchers to identify a population's likely resistance status by identifying the aphids' genetic lineage

The green peach aphid (*Myzus persicae* – GPA) is a major pest of many crops, with canola being particularly susceptible. In addition to feeding damage, the species is a carrier of more than 100 plant viruses– such as Turnip yellows virus (formerly known as Beet western yellows virus). It poses a serious management challenge as it evolves resistance to insecticides.

INSECTICIDE RESISTANCE TESTING

Previous research has identified resistance in Australian GPA populations to four out of the five chemical groups registered for use on canola. GRDC-invested research with **cesar** and CSIRO, which ran from 2015 to 2019, tested for resistance in specimens collected from more than 450 GPA populations.

The majority were found to have high resistance to synthetic pyrethroids and carbamates, as well as low-level resistance to neonicotinoids and organophosphates (Figure 1). High selection pressure, due to widespread use of neonicotinoid seed treatments in canola, poses a risk of further resistance evolving to this chemical.

Testing for resistance to sulfoxaflor following reported control failures in the Esperance region of WA also identified GPA populations with reduced sensitivity to this insecticide. These findings show the need for industry-wide adoption of resistance management strategies.

GENETIC PROFILING

GPA in Australia tend to reproduce asexually (giving birth to 'genetic clones'). This means that aphids generally have low genetic variation within populations.

Research was undertaken to analyse the different genetic profiles of GPA and associated mutations that confer resistance. These profiles now form a searchable database for known clones that allow researchers to identify the likely resistance status of a population by identifying the aphids' genetic lineage.

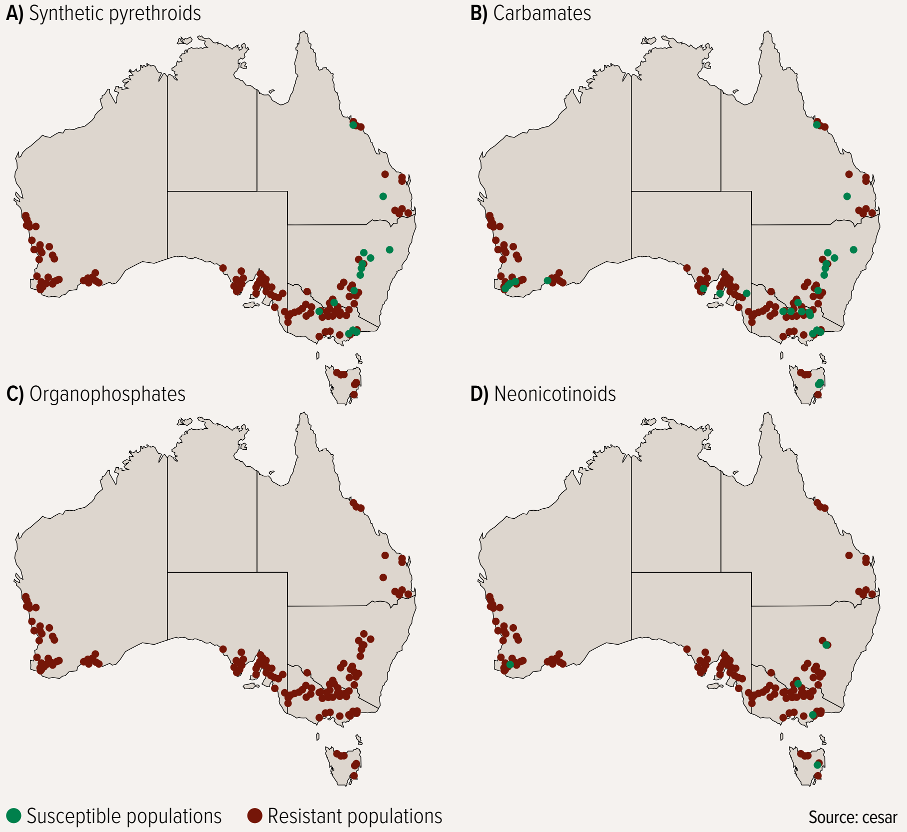
Management of a sticky trap network and subsequent genetic testing also allowed screening for the mutation 'R81T'. This is found in GPA populations overseas and confers near total resistance to neonicotinoids. Fortunately, this mutation was not identified in any of the aphids tested in Australia. However, there is a risk of this mutation becoming present in Australia either through local resistance evolution or introduction from abroad. This highlights the importance of remaining vigilant in identifying and tracking harmful genetic mutations.

NEW RESOURCES

Resources are available to help manage this aphid to reduce the risk of control failures and the evolution of resistance.

The *Green Peach Aphid Best Management Practice Guide – Southern* (www.grdc.com.au/green-peach-aphid-best-management-practice-guide-southern/) provides an overview of GPA management, with a new resistance management strategy to begin in 2021. This will be undertaken as part of a new GRDC investment. This new project will look to address knowledge gaps regarding virus risks, dispersal patterns of aphids and baseline sensitivity of soon-to-be registered chemicals. ☐

Figure 1: Maps indicating resistance status of aphid populations tested for synthetic pyrethroids, carbamates, organophosphates and neonicotinoids.



Source: cesar

GRDC Code CES2001-001 (CES00003)

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Cotton bollworm resistance management

By Dr Lisa Bird, Chris Shafto and Linda Drynan

KEY POINTS

- **Cotton bollworm resistance is being informed by surveillance and testing using a bioassay to determine the survival of insect larvae**
- **Growers are advised to continue to follow the *Helicoverpa Resistance Management Strategy***

■ Cotton bollworm (*Helicoverpa armigera*) larvae damage crops by feeding on developing seed; reducing yield and grain quality. This pest also has a track record for developing resistance in response to insecticide selection pressure, which makes it a challenge to control.

However, each year, with GRDC investment, the NSW Department of Primary Industries conducts cotton bollworm insecticide resistance surveillance to monitor changes in resistance frequency to major selective insecticides used to control *H. armigera* in grains. The program provides regionally specific information to help growers optimise the cost of effectively and sustainably managing this pest.

SURVEILLANCE PROGRAM

The program utilises F_2 screening to increase capacity for detecting resistance to indoxacarb, emamectin benzoate and chlorantraniliprole, which now have broad registration in pulses.

This type of screening is sensitive for all types of known and novel resistance and involves testing the grandchildren of moths from field populations to determine the genetic basis – dominant or recessive – of the resistance. Testing is done by exposing cotton bollworm larvae to a diagnostic concentration of insecticide known to be lethal to susceptible insects and assessing the survivors.

The advantage of using F_2 screening is its capacity for measuring underlying resistance by detecting non-conspicuous carriers of resistance genes, even when those genes are recessive and/or at low frequency in the population.

Due to this predictive capability, F_2 screening is an important tool in pre-emptive resistance management as it provides growers with an early warning system for identifying potential resistance hotspots. This ability to detect early stage resistance also improves industry preparedness by allowing management tactics to reduce economic losses before spray failures occur and by minimising further spread of resistance genes in the wider cotton bollworm population.

RESISTANCE RESULTS

Emamectin benzoate: No resistance detected to date.

Chlorantraniliprole: Resistance has been generally low (less than 0.5 per cent), apart from occasional levels of two per cent detected in southern and Central Queensland. In 2019-20 there was no resistance detected, indicating that genes for resistance to this insecticide are still rare in the *H. armigera* population.

Indoxacarb: Resistance has been of concern in recent years, with increases in both 2016-17 and 2018-19, particularly in northern and Central Queensland, where resistance was 2.4 times higher than in southern regions (see Figure 1). By the end of 2018-19, 14 per cent of the *H. armigera* population in northern and Central Queensland carried at least one gene for indoxacarb resistance. There was a significant reduction in resistance last season, with levels dropping from 10 per cent in 2018-19 to six per cent in 2019-20, with the most marked reductions in northern and Central Queensland.

This decline in resistance could be due to drought in 2018-19; the downturn in production meaning less spraying and reduced selection pressure for resistance.

It is recommended that growers continue to be guided by the *Helicoverpa Resistance Management Strategy*. This aims to slow the rate of resistance development to insecticides on which the grain industry relies. The strategy is based on best practice treatment windows, which are periods within the cropping calendar when insecticides can be used. They are designed to help growers rotate insecticides. This minimises exposure to products with the same chemical mode of action group and reduces selection pressure across consecutive generations of cotton bollworm. □

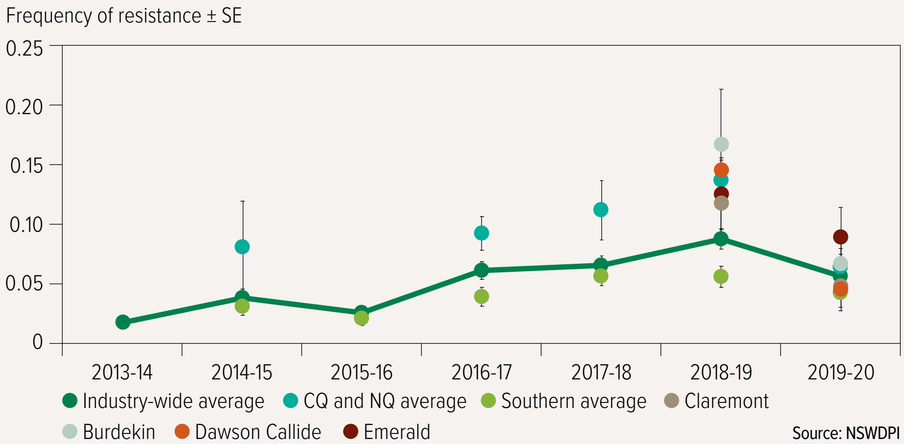
GRDC Code DAN1910-005

More information: www.grdc.com.au/GRDC-FS-Helicoverpa-resistance-management; Dr Lisa Bird, 02 7663 1128, lisa.bird@dpi.nsw.gov.au

Photo: Pulse Australia

Cotton bollworm (*Helicoverpa armigera*) is a major pest of not only pulses but also oilseeds, coarse grains and winter cereals. It is proving challenging to manage as it rapidly develops resistance to insecticides.

Figure 1: Annual average regional frequency of indoxacarb resistance in central/northern Queensland compared with the industry and southern averages ± binomial standard error (SE).



Mite resistance mapping sets up management

Redlegged earth mites are a pest of both pasture and grain crops and are proving problematic to manage as they have increasing rates of resistance to a number of insecticides.

Illustration: Elia Pirtle, cesar

By Leo McGrane and Dr Aston Arthur

KEY POINTS

- The rate of insecticide resistance to several chemicals is rising in redlegged earth mites (RLEM)
- Management of RLEM should follow the recommendations outlined in the national resistance management strategy and the recently released *Redlegged Earth Mite Best Management Practice Guide – Southern* (2020)

■ Redlegged earth mite (*Halotydeus destructor* – RLEM), a major pest of pastures and grain crops, is ubiquitous across Australia's southern cropping region. These mites cause significant damage during seedling establishment – when the crop is most vulnerable – resulting in the potential for considerable economic losses. Insecticide resistance to synthetic pyrethroids in RLEM in Australia was first detected in WA in 2006, followed by organophosphate resistance in 2014. Since these discoveries, resistance to both chemical groups has been found to be common across large areas of WA and has recently been discovered in south-eastern Australia.

In response to these resistance issues, a national resistance management strategy for RLEM was developed by the National Insecticide Resistance Management (NIRM) working group. The strategy recommends a range of cultural and chemical rotation methods to minimise selection for resistance while still effectively controlling RLEM. In addition, research through a GRDC investment was undertaken to find out how resistance in RLEM evolves and how widespread it is, and to improve resistance management strategies for this mite.

From 2016 to 2020, a multi-faceted GRDC research investment was undertaken by the University of Melbourne, the WA Department of Primary Industries and Regional Development, CSIRO and **cesar**. Key research components included extensive field surveillance of resistance across the known RLEM distribution, establishment of new methodologies to test for resistance, generation of baseline sensitivity data for neonicotinoids and new chemistries, as well as studies to determine whether there are any fitness penalties in RLEM that evolve resistance.

RESEARCH LESSONS?

RLEM resistance to both synthetic pyrethroids and organophosphates was found to be spreading across large areas of WA and to be present in several areas of SA and Victoria (see Figure 1). Using genomic techniques, the project team demonstrated resistance had evolved independently at multiple locations. This shows the importance of what individual growers do on their farm when it comes to RLEM management.

Further, the project showed that the frequency of synthetic pyrethroid resistance can increase rapidly in RLEM populations when exposed to these chemicals in the field, but no such increase was seen in the case of organophosphate resistance. This leaves the door open to control options using organophosphates, although there is potential for RLEM to evolve further resistance.

Researchers also found that diafenthiuron (for example Pegasus®), a recently registered RLEM insecticide for use in canola, was effective in controlling dual-resistant RLEM.

Insecticide resistance is based on changes that occur at the molecular level. The molecular mechanisms of organophosphate resistance in RLEM were found to be complex and are still not fully understood. It appears that multiple resistance mutations are contributing to organophosphate resistance and that these may vary in importance across the country.

Pre-emptive research was undertaken to develop robust and sensitive bioassay methodologies to test for shifts in sensitivity to neonicotinoids and diafenthiuron. This work also includes the establishment of baseline sensitivity data for RLEM, which will be important to industry for early detection of insecticide resistance to these chemicals.

Fortunately, there does not appear to be any field resistance to neonicotinoid seed treatments in Australian RLEM.

MANAGING RESISTANCE

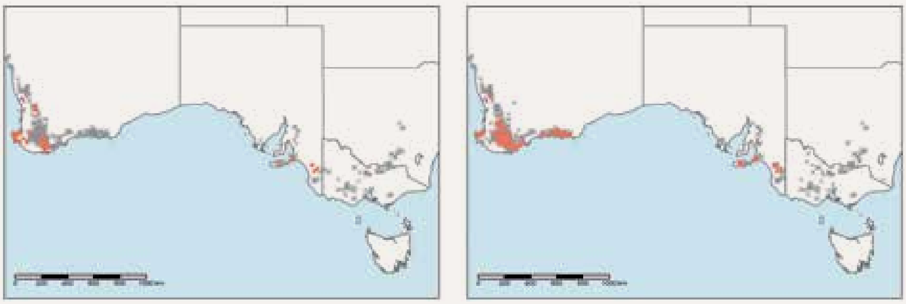
Management of RLEM should follow the recommendations outlined in the national resistance management strategy and the recently released *Redlegged Earth Mite Best Management Practice Guide – Southern* (www.grdc.com.au/redlegged-earth-mite-best-management-practice-guide-southern). This will help reduce the risk of further resistance evolution. Recommendations include avoiding unnecessary spraying, rotating between chemical groups, strategic spraying (for example, along fencelines) and using biological and cultural control strategies. □

GRDC Code UOM1607-003 (UM00057)

More information: www.grdc.com.au/FS-RLEM-Resistance-strategy, Dr James Maino, **cesar**, 03 9349 4723, jmaino@cesaraustralia.com

Figure 1: The known distribution of organophosphate and synthetic pyrethroid resistance in redlegged earth mites across Australia as of 2019.

A) Organophosphate resistance **B)** Synthetic pyrethroid resistance



× susceptible populations ● resistant populations

Source: Dr James Maino, cesar

Dismantling barriers to change

By Dr Sue Knights

KEY POINTS

- **Off-target impacts and concern about the environment, together with 'new blood' in a farming family, are providing some of the incentives for growers to modernise their invertebrate pest management practices**
- **More knowledge is required on beneficial insects to support decisions to reduce insecticide use**

In the absence of practice change, the continued heavy reliance on insecticides as the key management tool will increase production – and market – risks. These risks include the development of insecticide resistance, the depletion of natural enemies and the increased reliance on insecticides to control pests, and the potential for trade implications.

But practice change doesn't come with the flick of a switch. Growers need a clear incentive to change pest management practices and to consider novel approaches.

"Resistance is making control impossible or costly. Awareness of off-target impacts, concern for the environment, new blood in the farming family – these are the drivers for change," says Queensland Department of Agriculture and Fisheries (QDAF) principal entomologist Dr Melina Miles.

Dr Miles is based at Toowoomba and also spent many years working as an entomologist in Victoria.

"Essentially, we need a realisation that things have to change, or a desire to do better. Growers and advisers need support. They need to regularly check their information and discuss their plans and talk through whether what they want to do is reasonable and logical," she says.

"It may only be incremental change but it needs to be constantly upgraded until it becomes normal practice."

INSECT KNOWLEDGE STOCKTAKE

In 2018, under QDAF management with GRDC investment, the Independent Consultants Australia Network (ICAN) interviewed agronomists across Australia to collate industry understanding of invertebrate pests to form the basis of discussion at subsequent regional workshops.

The workshops, which included entomologists, focused on recommended best management practices, current industry practices and constraints to best management practice adoption and associated issues.

The agronomists were asked about the key pests in their regions, how they make control decisions and what further information or research they needed.

The list of invertebrate pests considered included earth mites, weevils, lucerne fleas, slugs, snails, slaters, earwigs, millipedes, wireworms, aphids (including the Russian wheat aphid and green peach aphid), Rutherglen bugs, cotton bollworms, diamondback moths, armyworms, mirids and green vegetable bugs.

"The need for more information on identification of pests and natural enemies, pest life cycles, ecology and thresholds which could inform their pest management decision-making was consistently raised by advisers," Dr Miles says.

Economic thresholds were identified as essential tools, and dynamic thresholds as highly desirable, and there was an appreciation that economic thresholds may change over time and need revision.

The second most important issue was information on beneficial insects (predators and parasitoids) and the effect they have on pest populations. The use of models to predict the number of natural enemies required to control pest populations was also identified as a valuable decision tool.

"We have a limited number of dynamic thresholds for pests and a good understanding of which beneficials are likely to suppress pest populations, but little – or no – work has been done to put the two together," Dr Miles says.

"The complexity of managing pests and preserving beneficials makes decisions about when and what to spray challenging. Support for decision-making around pests and beneficial impacts would probably increase confidence in holding off on sprays, and using more-selective insecticide options."

Photo: QDAF

Cotton bollworm feeding on a linseed plant. An incentive for change is required by growers to adopt novel integrated pest management practices to control pests such as these.

Photo: QDAF

Dr Melina Miles, principal entomologist, QDAF, using a beat sheet to look for insects in canola, supporting growers in their integrated pest management practices.

SUPPORT TO CHANGE

Not only is knowledge level a barrier to adoption of new practices, confidence and attitude to risk were also hindrances.

"Many advisers wanted their growers more involved in the decisions around pest management and to assume the risk associated with trying different approaches, or to at least drive or demand change in current management practices," Dr Miles says.

"Support for practice change in invertebrate pest management requires clear, practical recommendations and sustained RD&E for growers and their advisers as they develop their knowledge, skills and experience in doing pest management differently." □

GRDC Code DAQ1803-001

More information: Dr Melina Miles, 0407 113 306, melina.miles@daf.qld.gov.au; *Beneficials Northern Region Back Pocket Guide*, www.grdc.com.au/BPG-BeneficialInsects-North

Personal values underpin pest management decisions

Growers and advisers are well aware there is an over-reliance on chemicals for invertebrate pest control, but change requires insight into the personal drivers of pest management decisions

By Dr Jessica Lye, Bruce Howie

KEY POINTS

- Messages about insecticide resistance management and good insecticide stewardship need to be aligned with the value drivers that underpin farming communities
- Key values that drive growers' decision-making are responsibility for land and environment and pride in quality products
- Insecticide resistance management needs to have a foundation in long-term planning rather than short-term decision-making

Although resistance management and integrated pest management (IPM) practices are widely acknowledged as a key to industry sustainability, the adoption of these practices has been low. Innovative social science research is now aiming to change this by addressing growers' personal values.

With GRDC investment, the Birchip Cropping Group (BCG) together with the South Australian Research and Development Institute (SARDI), C-Qual Agritelligence and **cesar** are leading a project to explore how messages conveyed about insecticide resistance management – and more generally about good insecticide stewardship – could be aligned with farming community values. A growing body of research indicates that individual values and personal motivators have a significant and often unconscious influence on growers' decisions, as information alone has been insufficient to drive practice change needed to address rising pesticide resistance.

"Unpacking grower values is fundamental to determining people's motivation to change practices," says the project's manager, Kelly Angel.

"Once we are clear about these values we can design better information resources and customise activities to encourage practice change," she says.

"Growers operate in a complex and changing environment and we need to take stock of this when we consider how decision-making may be influenced:"

- The climate is variable, making it difficult to predict a pest outbreak and increased business risk.
- Grain enterprises are becoming increasingly large and mechanised and this leads to the need to improve the efficiency of operations.
- Export requirements for grain quality are extremely stringent, with zero tolerance for live invertebrates.
- Uptake of Insecticide Resistance Management Strategies (IRMS) is slow.
- There is an increased reliance on seed dressings, which are often neonicotinoids. Stronger restrictions are likely to be imposed on neonicotinoid use in the future and restrictions will follow on other chemical classes.

INSIGHTS INTO VALUES

To obtain insights into the values driving growers' decisions, a key question was addressed: why do growers love farming?

Two activities were undertaken to obtain these insights. The first was a series of focus groups with selected groups of growers across the southern region, and the second was a short survey by Cultural Dynamics Strategy & Marketing Ltd to reveal what they refer to as 'Values Modes'. The aims were to capture values that underpin decision-making and classify people into behavioural groups (Table 1).

"Four key reasons for farming emerged: responsibility for land and environment; continuity of farming and family tradition; rewards and demonstration of success; and passion for agriculture and pride in quality products," Ms Angel says.

"Discussion of the need for practice change on-farm has commonly been focused around increasing financial returns, such as through yield increases or greater efficiencies. This is important, but for some growers, may not be the primary trigger for stimulating interest in a new concept or motivating practice change."

DESIGNING EXTENSION FRAMEWORK

Contemporary decision-support information and activities are now being underpinned with grower values at the foundation (Step 3, Table 2).

"Each part of the framework plays an important role in leading to a point where growers can make a values-based and rationality-based commitment to implement the desired behaviours. When the necessary support systems are in place to guide the implementation, the ultimate outcome is greater potential of achieving change that will be maintained and becomes part of normal practice," Ms Angel says.

INFORMATION AND ACTIVITIES

The project has generated several best management practice guides for significant pests and delivered several reactive sessions at field days, utilising **cesar** and SARDI experts presenting on topics requested by growers. It has also produced a series of podcasts. Resources and activities have been arranged to provide delivery mechanisms that suit different styles of learning or accessing information.

"BCG has also focused on increasing awareness of the challenges that come with maintaining the 'status quo', which has led to growers thinking more about

Table 1: Summary of growers' key motivators to farm expressed by participants at four focus groups.

Lake Bolac (Victoria)	Birchip (Victoria)	Naracoorte (SA)	Hart (SA)
Continue family tradition	Satisfaction in running a family farm	Long family history of family farming	Continue family tradition
Love farming – variety and challenges	Enjoy growing things	Passion for agriculture	Love farming
Continuity	Pass the land on no worse or, hopefully, better	Continuous learning	Future opportunities for the family
Environmental improvement, especially now with children	Rewards from meeting the challenges of our environment	Maintaining healthy and sustainable farm	Maintain the legacy and hope to make a living out of it
Satisfying and rewarding	Care of the soil	Big-picture, responsible environmental management	Leave the farm better for the next generation
Always being challenged by whatever comes around the corner	Meeting the challenges of every new season	Satisfaction of producing quality products	Enjoy the challenge and want to keep improving
Enjoy new ideas but becoming more cautious	Pushing boundaries	Doing things right	Doing the best with what we have
Achieve financial goals	Can make income from what I love	Profitability of a good family enterprise	Try to be profitable amidst the seasonal challenges
Independence – working for yourself	• Working outdoors and in the crop • Trying new things and new research • Producing quality, market-ready produce with safe methods • Analysis and interaction of systems • Making decisions on the fly	• Love being outdoors • Give back through producing • Seeing crop develop to maturity is exciting	

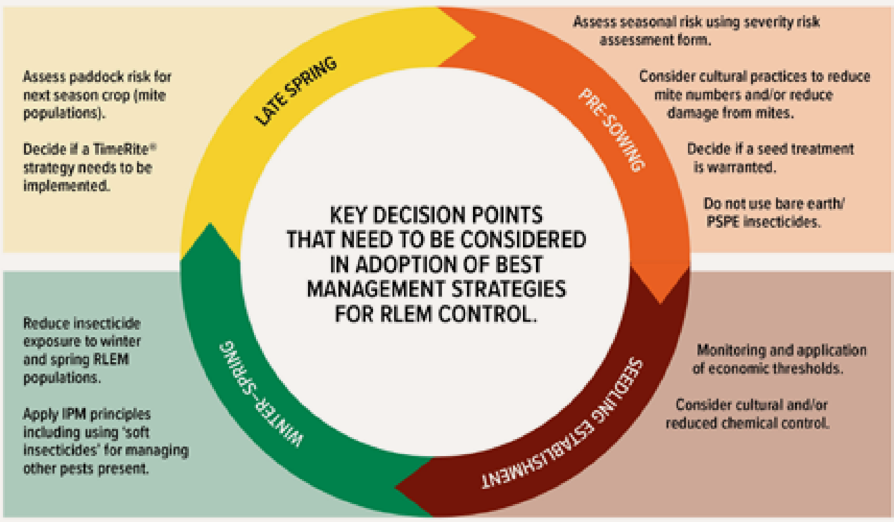
Source: C-Qual Agritelligence and BCG

Table 2: Simplified extension framework.

Framework stage	Step
1	Determine desired actions
2	Establish the knowledge base
3	Determine motivations and values
4	Design extension activities and materials
5	Prepare support materials
6	Train support personnel
7	Prepare promotional material
8	Facilitate enquiry/action
9	Conduct extension activity
10	Ensure that support services are activated and available
11	Monitor implementation and desired actions
12	Review and revise

Source: C-Qual Agritelligence

Figure 1: Extract from the *Redlegged Earth Mite Best Management Practice Guide – Southern Region* showing the key decision points that need to be considered in adoption of best management strategies and best insecticide stewardship.



Source: GRDC

why they are doing things rather than just what they are doing," Ms Angel says.

Figure 1 is an example of the decision points that need to be considered in the adoption of best management strategies; in this case for redlegged earth mite control.

DECISION INFLUENCES

While this project included focus groups and surveys to investigate grower value drivers, adviser value drivers and challenges remains to be explored. Adoption of change is also influenced by long-term sustainability issues. These include seasonality of pests, limited options for management, and demands for high-quality products with minimal, if any, damage from insects or the presence of live insects in produce. Extension materials need to acknowledge these challenges, as well as recognise that motivators other than profit, such as responsibility for land and environment and pride in quality products, are also behavioural drivers to be considered within extension frameworks.

"Pest management practices are lagging behind approaches we have for weed management. We have fewer tools and there are still research gaps to be filled," Ms Angel says. ☐

GRDC Code BWD1805-006

More information: Dr Jessica Lye, 0401 555 567, jlye@cesaraustralia.com

Insect pests of establishing canola in New South Wales can be found on the GRDC website as an interactive PDF.

‘Community of learning’ lifts pest management confidence

Why pay for pest control services when you can have them for free? Natural enemies are part of integrated pest management, but adoption needs a helping hand

By Dr Jessica Lye, Phil Bowden and Carl Larsen

KEY POINTS

- Early-season canola pests may be better managed through integrated pest management (IPM)
- IPM adoption has been slow as it is knowledge-intensive but support through a ‘community of learning’ may accelerate uptake
- Tracking confidence in growers’ use of IPM is showing a community approach works

■ Integrated pest management (IPM) is often described as a knowledge-intensive method of protecting crops. To grow a crop using IPM principles, growers must understand pest biology and life history, crop susceptibility, pest monitoring and identification, the most appropriate chemical control options and how to reduce pest habitat suitability.

Knowing the natural enemies that can help keep pest populations under an economically damaging level and ensuring that farming practices are benign (or beneficial) towards these species are also crucial elements of IPM.

A recent extension project, led by Bowden Rural Services, FarmLink, **cesar** and RM Consulting Group (RMCG), supported NSW canola growers and advisers in a ‘community of learning’, through a season-long IPM training program. The program began before planting in February 2019, as the focus was identifying and exploring management options for early-season pests such as aphids, lucerne fleas, mites, weevils, cutworms, false wireworms and slugs.

LEARNING TOGETHER

Initial pre-season IPM workshops were held with an emphasis on identifying pests and beneficial species and designing an integrated plan to trial in the lead-up to, and following, planting.

While certain crop pest species are present in or near a paddock throughout the entire plant growth cycle, they can be more problematic during early growth stages when canola seedlings have not produced enough leaf material to compensate for intense insect-feeding damage. Further, just as plants have different nutritional needs according to their stage of growth, the needs of invertebrate pest species can also vary. Therefore, understanding when a pest may be particularly ‘voracious’ on a crop such as canola can also help in making control decisions.

Follow-up events, including a paddock walk and webinars, further investigated IPM options for pests that had been found during the early part of the season, and also explored the impact that monitoring and management can have on canola establishment and growth. More than 400 people engaged in the project activities.

Each extension activity aimed to build on the previous learning opportunity and provided a platform for curious and like-minded participants to meet through the season and discuss IPM options.

Changes to confidence and adoption among participants were tracked throughout 2019 and 2020 by RMCG. It was found that, after completing the workshops, almost all respondents stated that they intended to use or advise on IPM practices in their farming system.

NOVEL INTEGRATION OF LEARNING

The value of this approach was threefold:

- Real-time monitoring of events, rather than retrospective evaluation at the end of the project, enabled tracking of changes to attitude, confidence and adoption as each extension activity was conducted.
- A ‘trial it and see’ approach within a community of learning supported local groups in moving forward in learning and sharing together.
- Combined know-how of research entomologists, field entomologists and extension specialists produced high-quality learning materials and advice.

Those wanting to learn more about canola pests in NSW growing areas can refer to an invertebrate pest identification and management guide developed by **cesar**, *Insect Pests of Establishing Canola in New South Wales* (www. grdc.com.au/resources-and-publications/all-publications/publications/2019/insect-pests-of-establishing-canola-in-nsw). □

GRDC Codes CES1810-001, FLR1810-001

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DIGITAL TOOLS AT HAND

By Dr Hazel Parry and Dr Madeleine Barton

Digital technology is integrating knowledge on invertebrate pests, weather conditions, beneficial insects and crop dynamics to inform in-paddock decisions.

As knowledge increases about the life cycle, damage potential and distribution of emerging crop pests such as earwigs and millipedes, existing knowledge of well-studied pest species such as aphids needs to be drawn upon in support. For example, understanding when aphid population outbreaks may occur, and what support beneficial insects might provide to control these outbreaks, is an important step towards optimising the time of spraying to avoid the loss of beneficials and maximise grain yield.

COMPUTER SIMULATION

Forecasting pest outbreaks requires knowing how their movements and population dynamics are affected by climatic factors, such as temperature and rainfall, as well as the dynamics of the crop itself. Accounting for the responses of beneficial insects to these factors, as well as the pest and interactions between them (for example, parasitism rates), can give valuable insights into the potential for biological control. Researchers have now developed a computer model that can simulate the population dynamics of green peach aphid and its parasitoid wasp *(Diaeretiella rapae)* across southern grain growing regions. Such integration of knowledge through modelling is bringing us closer to digital solutions that growers can use to protect crops.

VISION FOR THE FUTURE

Digital decision support for pest and disease control across Australia has been estimated to have the potential to unlock $1 billion of economic benefits. Improved access to computers, handheld devices and the internet's increasing reach into remote areas are making such tools more accessible.

How might computer simulation models evolve into 'digital IPM' tools? Picture this: a grower is in a canola crop. A notification flashes on their mobile phone, alerting to a report on the latest insect monitoring data sent from multiple sensors around the farm indicating early signs of green peach aphid activity. The grower opens the insect pest management app. Live data from the Bureau of Meteorology, local weather stations and current crop information is fed into the model which provides a detailed, short-term forecast of what is likely to happen next for any established aphid colonies. The app also indicates there is a high level of beneficial insect activity in and around the field, based on automated image recognition of parasitic wasps in sticky traps. This, too, is fed into the model, which reveals there is low risk in relying on parasitoids to deal with any potential aphid outbreaks, and therefore no real need to spray pesticide.

MAKING 'DIGITAL IPM' REALITY

This technology almost entirely exists already. The problem has been the need to open and crosscheck data from multiple apps and models. However, Australian researchers have developed a flexible digital framework known as Digiscape, which can integrate multiple types of data (from automated insect traps to weather stations) with forecasting models into user-friendly, decision-support tools (Figure 1). This is a good example of the potential of digital technology for IPM now being unlocked. □

GRDC Code CSP1501-002 (CES00059)

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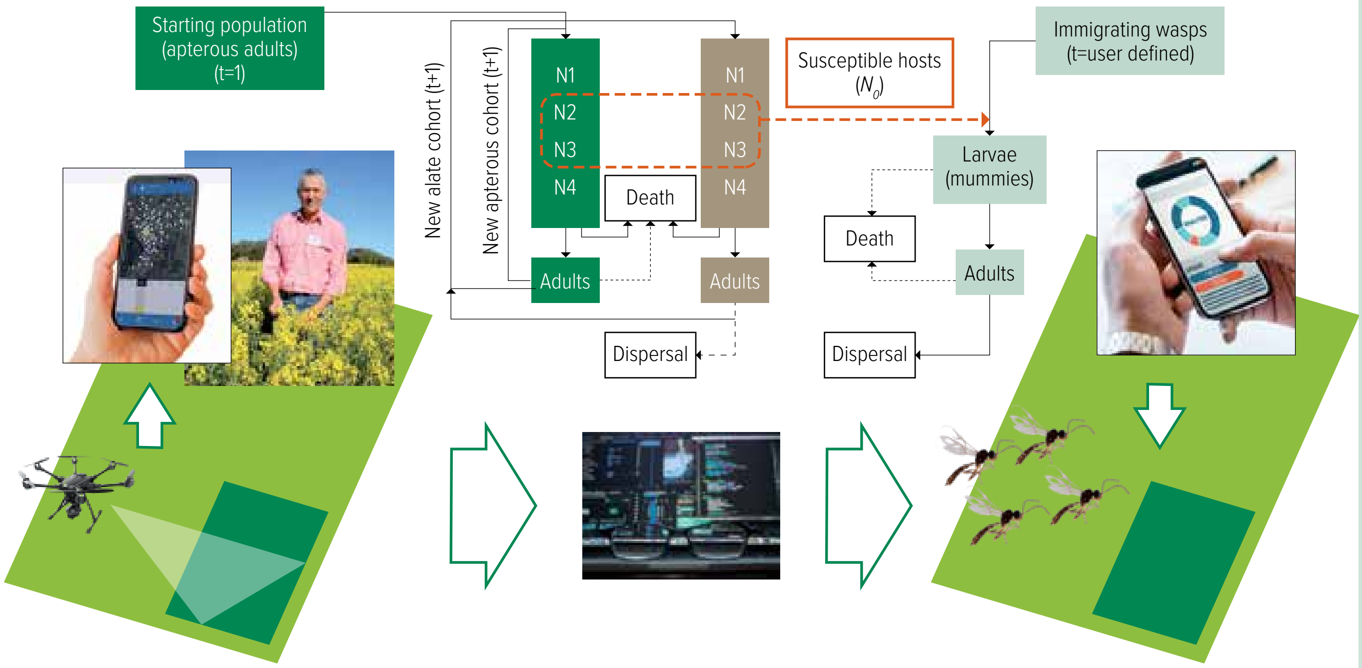
Figure 1: A schematic of 'digital IPM': integration of monitoring, forecasting and decision-making across multiple devices and platforms to provide real-time pest management solutions



1. Monitoring. Automated field data collection and pest outbreak detection.

2. Forecasting. Integration of field data with climate and topographic data to inform an ecological model of pest and beneficial insect population dynamics.

3. Decision-making. Estimated yield loss and optimised management strategies output from the 'digital IPM' system.

Source: CSIRO

Native plants a novel ally

Photo: GRDC

Lesser grain borer (*Rhyzopertha dominica*) is a major pest of Australian stored grain that has developed resistance to many insecticides and is being targeted by Flavocide™ in testing by QDAF.

By Dr Sue Knights

KEY POINTS

- A new mode of action insecticide, Flavocide™, has potential as a residual grain protectant
- Combining Flavocide™ with other insecticides may increase their efficacy and reduce treatment rates
- Flavocide™ is several years from market as it undergoes further field trials and regulatory steps

■ Increasing levels of insect resistance to pesticides are a significant problem as the number of available pesticide modes of action (MOA) becomes limited. However, the quintessentially Australian eucalypt has provided the inspiration for the development of a nature-derived chemical with a new MOA that has potential as an insecticide in the grains industry.

Flavocide™ is a synthetically created, beta-triketone molecule patented by Bio-Gene Technology. The molecule was identified by screening native flora for chemicals with insecticidal properties. It occurs naturally but in small amounts in some eucalypt species. To address this limitation, Bio-Gene Technology worked with CSIRO Advanced Manufacturing to develop a new scalable chemical synthesis process, which has increased production compared with extraction from plant materials.

GROWER INPUT

"Having GRDC involved from an early stage ensured grower relevance in the development of Flavocide™ as another tool critical for managing insect pests resistant to grain fumigants and protectants," says Bio-Gene Technology chief executive officer Richard Jagger.

Fumigants such as phosphine are volatile and used to disinfest grain, whereas grain protectant products are used to prevent infestation of insect-free grain and provide longer-term residual protection in storages. Flavocide™ is set to enter the grains industry as a product for residual protection.

"We have been discovering new knowledge as we develop Flavocide™. In addition to being an insecticide, we have seen synergistic effects when paired with certain classes of chemistry, suggesting benefits when used in combination," says Bio-Gene Technology's executive director of R&D, Peter May. Laboratory studies and field trials in collaboration with BASF, the Queensland Department of Agriculture and Fisheries (QDAF) and GRDC aim to demonstrate further effectiveness of Flavocide™ against both susceptible and resistant strains of lesser grain borer, saw-toothed grain beetle, rusty grain beetle, rice weevil and flour beetle, especially when used in combination with organophosphate and pyrethroid-based products. The project aims to determine optimum rates of Flavocide™ combination treatments to improve the scope of treatment as well as potentially to reduce application rates required for control.

RESISTANCE MANAGEMENT

Flavocide™ brings another mode of insecticidal activity to grain storage pest management, offering the means to control resistant insects and extend the use of chemistries that are under threat from pest resistance.

"It has been demonstrated to work differently to currently used grain protectants and therefore offers the opportunity to complement these products," Mr May says.

Flavocide™ will be available commercially after further field testing and other regulatory-enabling studies have been completed. □

GRDC Code BGT1911-001

More information: Richard Jagger, 0418 125 646, richardj@bio-gene.com.au; Peter May, 0412 251 016, peterm@bio-gene.com.au, www.bio-gene.com.au/flavocide

Photo: Bio-Gene Technology Ltd

The team behind the new research collaboration to test a new mode of action for stored grain pests. From left, Bio-Gene Technology program manager Dr James Wade, QDAF post-harvest grain protection specialist Philip Burrill, operational farm hand Richard McKillop, QDAF principal research scientist Dr Manoj Nayak, Bio-Gene executive director Peter May, QDAF researcher Rajeswaran Jagadeesan and QDAF principal research scientist Greg Daglish.

Protectant option in synthetic amorphous silica

By Tony Eyres

While silica-based products such as diatomaceous earth have long been known to have insecticidal properties, recent research into the efficacy and mode of action of a synthetic form – synthetic amorphous silica (SAS) – has added to the understanding of its effectiveness as an insect control agent. SAS is set to have broad application in grain held in storages on-farm, at up-country facilities and in processing facilities. It is a food-grade product already in use, being non-toxic to humans, other mammals, birds, fish, plants and the environment generally.

SAS GRAIN APPLICATION

The potential use of SAS along the grains value chain stands to address two major issues: First, as on-farm grain storage infrastructure continues to increase, so does the challenge of insect resistance to grain protectants and the fumigant phosphine. This weakening of control methods is exacerbated by the use of older, difficult-to-seal storages and temporary facilities, not as suitable for fumigation. SAS could be used in these circumstances.

Secondly, grain customers are keen to further understand the role of SAS as an insect control agent, with grain millers and barley maltsters particularly interested in a silica-based product other than diatomaceous earth. They are keen to explore the potentially lower application rates of SAS and the advantage this gives in grain handling and processing.

INNOVATIVE RESEARCH

Initial research on SAS was funded through the Plant Biosecurity CRC and is owned by the Australian Plant Biosecurity Science Foundation. IP protection mechanisms are in place and Davren Global has a mandate to commercialise the technology. Further work on variables such as field environment, commodity type, insect species and SAS physio-chemistry is being done.

Using conventional, up-country, grain storage and handling equipment, these commercial specifications and optimal formulations are being resolved. Plus, electron microscopy tools have been used to learn the mode of action for SAS.

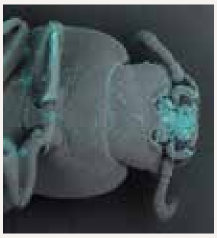
A library comprising more than 2000 diagnostic images has been compiled and annotated using Scanning Electron Microscope (SEM) and matching Energy-Dispersive X-ray Spectroscopy (EDS). These confirm the presence of silica as SAS on target insect species after contact with SAS-treated grain.

Figure 1: Overlaid images from scanning electron microscope and energy dispersive x-ray spectroscopy of four grain storage pests.

The fluorescent colour indicates successful transfer of synthetic amorphous silica from the grain commodity to the pests. Magnification x60

Lesser grain borer (*Rhyzopertha dominica*)

Rice weevil (*Sitophilus oryzae*)



Red flour beetle (*Tribolium castaneum*)

Saw-toothed grain beetle (*Oryzaephilus surinamensis*)

Source: Davren Global

INDUSTRY SPECIFICATIONS

A key objective of the research is to achieve effective SAS kill rates at low application levels; ideally less than 100 grams per tonne for most grains, to avoid problems during grain handling and milling (Figure 2). Application rates greater than 100 grams per tonne can affect the bulk density and therefore handling properties of grain. Challenges such as these have plagued naturally occurring amorphous silica products such as diatomaceous earth.

PARTNERSHIPS

In Australia, Davren Global's work is supported with investment from GRDC and Sunrice. The Australian Centre for International Agricultural Research is also funding Davren Global's collaboration with the Tropical Pesticides Research Institute in Tanzania, with a focus on corn. This recognises the potential application for SAS in subsistence farming operations, which suffer grain losses of up to 70 per cent due to pest infestations. These R&D investors are providing the initial financial support to kick-start product development.

Davren Global is building additional partner relationships to leverage industry demand to further develop the core SAS products, technologies and solutions from the lab to commercial reality in three to five years. □

GRDC Code DVG1908-001

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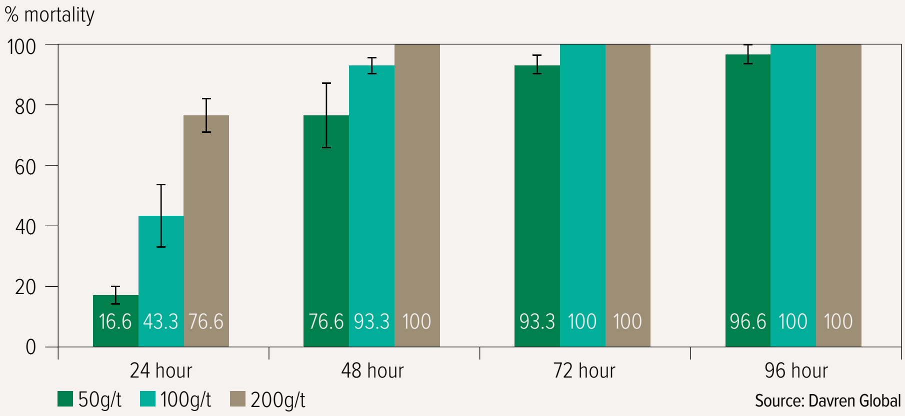
Figure 2: Red Flour Beetle (*Tribolium castaneum*) knock down rate (per cent mortality) trial in sorghum at 50, 100 and 200 grams SAS/tonne.



Source: Davren Global

Grass fungus a potential ally against pests

Work on endophytic fungi, which enhance the productivity of pasture grasses, is being adapted to cereals to see if the mutualistic relationship can improve the tolerance of cereals to pests and drought

By John Caradus and David Hume

KEY POINTS

- **Inoculating wheat with strains of *Epichloë* fungi has been shown to reduce damage by the Argentine stem weevil and wheat sheath miner**
- **Agronomic trials with endophytic rye have shown increases in grain yield of up to 25 per cent under some treatments and indicate that increases of about 20 per cent may be realised for wheat**

■ New Zealand researchers are translating their successes with endophytes in pasture species to wheat in expectation that the mutually beneficial relationship could improve wheat resilience in the face of pests and climatic pressures. The work is being done with investment from GRDC, Grasslanz Technology, the Foundation for Arable Research and the New Zealand Government.

Temperate grasses (ryegrass and tall fescue) have been inoculated with *Epichloë* fungal endophytes to improve yield and persistence through providing 'natural' protection against pest, diseases and drought. In fact, selected *Epichloë* endophytes have been so effective within the pasture grass industry that they are now a standard ingredient for high-performing pastures.

The aim of this research is to identify *Epichloë* isolates taken from wild relatives of cereals, then inoculate strains of this endophyte, with appropriate beneficial properties, into elite cereal genotypes.

This process leads to functional associations between elite cereal cultivars (wheat and rye) and endophytic *Epichloë* fungi, to protect cereals from pre and post-harvest invertebrate pest attack and potentially enhance their tolerance to abiotic stresses.

The endophyte produces bioactive molecules providing these beneficial effects; these are being tested to ensure they are not harmful to humans or livestock and will not impair the nutritive or health characteristics of cereal forage or grain.

FINDINGS

Many *Epichloë* isolates from grasses in the genera *Hordeum* (of which barley is a member) and *Elymus* (of which wheatgrass and wild rye are members) have been assembled from worldwide collections and characterised.

These have been found to have an extensive range of secondary metabolites which have known bioactivity against a range of pests and disease.

Inoculation of *Epichloë* endophyte into rye (*Secale cereale*) has been successful, with good transmission rates through seed.

Endophyte bioactivity against insect pests in endophyte strain AR3002-inoculated rye resulted in lower levels of damage from Argentine stem weevils (*Listronotus bonariensis*), wheat sheath miners (*Cerodontha australis*) and thrips (*Frankliniella spp.*) than in endophyte-free rye.

A small grain storage trial has shown some suppression in the total number of saw-toothed grain beetles (*Oryzaephilus surinamensis*) after three months.

Wheat seed has been generated from plants that were infected with the same endophyte strain, identified as the first non-toxic endophyte to give a normal plant phenotype.

A collaboration at the University of Adelaide has seen four endophyte strains inoculated into 20 selected experimental substitution/addition wheat lines (supplied by Tottori University, Japan). The next step will be to examine these wheat lines for effective endophyte transmission and bioactivity and then cross with modern wheats.

INDUSTRY IMPACTS

AR3002-inoculated wheat seed has been tested in mouse feeding trials. So far there is no evidence of any toxicity or animal health issues associated with this *Epichloë* endophyte strain in the grain. Similarly, ruminants have safely grazed or consumed forage, silage or grain of rye inoculated with AR3002 endophytes.

While agronomic trials with endophytic wheat are still to be undertaken, agronomic trials with endophytic rye have shown increases in grain yield of up to 25 per cent under some treatments. A similar result for endophytic wheats would raise the average grain yield by 20 per cent. □

GRDC Code GTL1709-001

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Photo: Grasslanz Technology

Successful work on endophytic fungi (in the genus *Epichloë*), which enhance productivity and persistence of pasture grasses, is being adapted to cereals by New Zealand researchers to see if the mutualistic relationship can enhance the tolerance of cereals to pests and drought in Australia. Experimental wheat (Chinese Spring) infected with AR3002 endophyte in preparation for grain production.

Chance finding points to new biocontrol for snails

Some people never lose their childhood fascination for slugs and snails, and it transpires that if you have a high-level understanding of invertebrate pests and ecology you might be on to something valuable for Australian grain growers

By Associate Professor Helen Billman-Jacobe

KEY POINTS

- Snails and slugs are significant economic pests of grain crops and until now have been controlled by molluscicides
- The main molluscicide used is metaldehyde and its use may be restricted in Australia due to concerns about toxicity to mammals and birds
- A chance observation of a natural parasite in a captive slug population has led to the development of a novel biocontrol agent

■ A chance finding by an observant scientist has led to the discovery of a potential new biocontrol method for pest slugs and snails.

Scientists researching the biology and ecology of grey field slugs (*Deroceras reticulatum*) as a precursor to developing biocontrols, were trying to breed them in the laboratory, but found the slugs kept dying.

Closer examination revealed parasitic protozoa were killing them. Protozoa are microscopic single-celled organisms. This particular one was a ciliate protozoan, meaning it was covered in hairs (called cilia). The protozoan, *Tetrahymena rostrata*, is a natural parasite of slugs and snails; it occurs naturally in Australia and other parts of the world.

GRDC then invested in a new project with the University of Melbourne aimed at using *T. rostrata* as a biopesticide. The Melbourne team focused its efforts on the major pest, the grey field slug; however, recent experiments showed the protozoan can kill several species of slug and the effects on snails are also being evaluated. This means that the protozoan's potential as a biocontrol agent may be far-reaching.

Snails and slugs are major crop pests, damaging plant seeds, seedlings, underground tubers, leaves and fruit.

Metaldehyde has been the molluscicide of choice for many years, commonly applied in pelleted baits. However, the use of metaldehyde may be restricted in the future due to concerns about its toxicity to mammals and birds.

Pesticide stewardship programs aim to reduce the need for metaldehyde but more options are needed for mollusc control. Researchers at the Asia Pacific Centre for Animal Health at the University of Melbourne are finding innovative ways to fight pest slugs and snails.

INSIGHT AND OBSERVATION

Despite the importance of terrestrial molluscs, including grey field slugs, in agriculture and horticulture, their biology and ecology are relatively poorly understood. This is why the scientists were testing whether they could use genetic technology to shut down slugs' metabolisms. They required a regular supply of slugs for laboratory testing, so started breeding grey field slugs (*D. reticulatum*) in the laboratory.

Collecting grey field slugs from the wild for experiments is labour-intensive, subject to seasonal availability, and there is a lot of variation in the health of collected animals. Colonies of laboratory-reared *D. reticulatum* were established to provide a predictable supply of animals for experiments, but then the protozoan *T. rostrata* became a factor.

T. rostrata cells go through several stages of development and can be either parasitic or free-living. Their life cycle has been exploited by researchers, who have now developed scalable production of the free-living form, and determined which developmental form is the most infective.

Researcher Dr Ruth Haites has studied the life cycle closely and can grow the cells in large numbers and then stimulate them to form cysts, allowing them to survive outside the host. These cysts are then primed to release the most infective protozoa.

Laboratory trials show *T. rostrata* kills young slugs within days of exposure. When the protozoa exit their cysts, they find a slug and kill it.

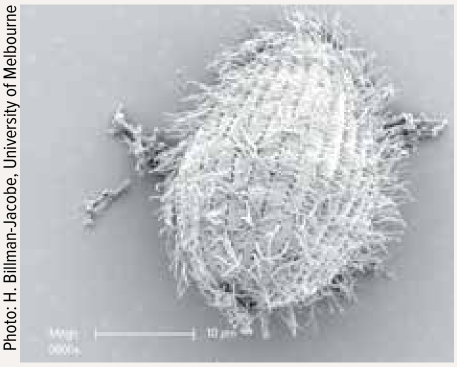

Photo: H. Billman-Jacobe, University of Melbourne

Parasitic ciliate protozoan (*Tetrahymena rostrata*) seen under a scanning electron microscope at 5000x magnification. A natural parasite of snails and slugs in the wild, it is now being exploited as a biocontrol agent.

Photo: Mike Dyall-Smith, University of Melbourne

Associate Professor Helen Billman-Jacobe collecting slugs and snails in Wagga Wagga, NSW.

TESTING AND SCALING UP

The research group is undertaking host range and safety testing and is scaling up production to start the next phase of trials. The group aims to have products on the market in the next few years.

The best time to apply the protozoa to the soil needs to be determined, but it is predicted that it will be in autumn and spring when large numbers of slug and snail eggs hatch and the molluscs are still on the ground. □

GRDC Code UOM1706-001 (UM00059)

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Renewed attempt at biological control of pointed snails

By Dr Valerie Caron, Dr Kate Muirhead, Dr Kym Perry, Dr Yassine Fendane, Professor Mohamed Ghamizi and Thierry Thomann

Photo: CSIRO

Moroccan parasitic flies are proving their potential as biocontrol agents of Australian pointed snails. Professor Mohamed Ghamizi (left) and Dr Yassine Fendane with parasitic fly (*Sarcophaga villeneuveana*) and pointed snail (*Cochlicella acuta*) colonies at Cadi Ayyad University in Marrakesh, Morocco.

KEY POINTS

- A parasitic fly was introduced in the early 2000s to South Australia to control pointed snails, but failed to spread
- New research, with Moroccan scientists, has identified more efficient parasitic fly strains for pointed snail control

Land snails can be problematic contaminants in Australian crops as they have a habit of climbing to higher ground as temperatures rise, often congregating in grain heads in spring and being harvested with the grain. These snails cost growers millions of dollars annually through cleaning and grain downgrading.

While bait and mechanical methods can reduce snail populations, management often requires ongoing effort, as the snails are resilient. There is no 'silver bullet', but a possible new control has emerged in the form of a biocontrol agent, the Moroccan fly *Sarcophaga villeneuveana*.

A biological control program for pointed snails (*Cochlicella acuta*) was instigated by CSIRO and the South Australian Research and Development Institute (SARDI) in the 1990s, with investment from GRDC. A fly parasitoid from France, *Sarcophaga villeneuveana* (formerly *S. penicillata*), was introduced on the Yorke Peninsula in SA in the early 2000s.

This fly lays its larvae on host snails. The larvae then enter the shell and feed on the snail, killing it. Although successfully established in a small area, *S. villeneuveana* has spread little in the past 15 years and parasitisation levels remain low. Researchers are now looking to see if another strain could be more effective against these snails.

MOROCCAN FLIES ARE BEST

By teaming with Cadi Ayyad University in Morocco, and with funding from GRDC, CSIRO and SARDI, researchers compared strains of the fly *S. villeneuveana* (Figure 1) from various regions (France, Morocco and Spain) and their hybrids to the now-established Australian fly strain, through work at the CSIRO European Laboratory in Montpellier, France.

Thousands of Australian pointed snails were sent to France, where they were offered to the different fly strains, and the results are promising. Under laboratory conditions, the Moroccan fly and the Moroccan x Spanish hybrid fly parasitised more *C. acuta* than did the Australian fly. This indicated that other fly strains may be more efficient at parasitising *C. acuta* than the fly strain already established, and that further field introductions could help to control *C. acuta*.

As pure Spanish flies performed poorly and the French and Moroccan populations of *S. villeneuveana* were shown to be the most genetically different, the decision was made to focus further research on the Moroccan fly.

Photo: CSIRO

Figure 1: Parasitic fly (*Sarcophaga villeneuveana*) with pointed snails (*Cochlicella acuta*) in the field.
Source: Yassine Fendane, Morocco

HOST-SPECIFICITY TESTING

Under Australia's biosecurity laws, biological control agents such as these flies must undergo strict testing and assessment before being released from quarantine.

SARDI obtained an import permit from the Australian Department of Agriculture, Water and the Environment for multiple shipments of *S. villeneuveana* from Morocco into its quarantine facility. The first shipment of the Moroccan strain was received in January 2020 and a colony was successfully established.

Six Australian native and five exotic snail species were collected from regional SA and WA for host-specificity testing. Testing of the Moroccan strain of *S. villeneuveana* is now in progress. Depending on the results, an application for a release permit will be made to the Department of Agriculture, Water and the Environment. If successful, SARDI will coordinate the introduction and field release of the flies. ☐

GRDC Code CSP1706-012 (CSE00061)

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Snail trail entrapment

Photo: Andrew Weeks, cesar

Round snails, including white Italian snail (*Theba pisana*, pictured) and vineyard snail (*Cernuella virgata*), are major harvest pests of grain and the focus of investigations for biological control.

Snail infestations can affect grain quality; however, an innovative control method may provide a management solution

By Kate Ballard and Associate Professor Scott Cummins

KEY POINTS

- Round snails can be a serious contaminant of grain at harvest with the potential to threaten market access
- Round snail mucus is being examined for compounds that could be used to control the pest

A forensic investigation of snail slime is underway to see whether this excrement can be used as a control medium. The approach is combining improved snail ecology knowledge with sophisticated chemical analysis.

Four species of European snail are dormant on the stalks of crops during the summer, and they may pose a challenge to the harvest. These species include the white Italian snail (*Theba pisana*) and the vineyard snail (*Cernuella virgata*), known collectively as the round snails, which are the focus of investigations to identify approaches for safe removal.

Research since the early 1980s has led to a number of control methods, which are used in an integrated approach to manage snail numbers. This research has been largely centred around baiting, which is not only expensive but can also be hit-and-miss. As snails are not attracted to baits, success relies on snails encountering baits, necessitating a high density of bait spreading.

SNAIL ECOLOGY

A feature of snail behaviour that has not yet been extensively investigated is their mucus trail. Previous research on other species has shown that land snails will follow mucus trails of their own species to find a mate or to aggregate.

The question raised is: can these trails be used to lure snails into a trap?

Preliminary work on this project with the garden snail (*Cornu aspersum*) has revealed that the mucus trail is far more complex than its appearance suggests. With GRDC and University of the Sunshine Coast investment, this project is the first to investigate the components of snails' mucus trails to determine whether they contain chemicals known as pheromones that may be used for communication.

Animal pheromones can be either proteins or airborne volatiles. It has been discovered that some marine molluscs use proteins as pheromones, so analysis of protein components of the mucus trail is the first step in unravelling the mystery of snail slime.

Comparison of the protein components of mucus between the breeding season (May–October) and the inactive season (November–April) will help to narrow down which chemicals are present in breeding season mucus that are not there in inactive season mucus, and therefore may function as a mating pheromone. Researchers can also get information from the amino acid sequence, which can lead a protein to be a likely candidate pheromone. To supplement this, gene expression will also be compared between the two seasons, which will provide additional information about changes in the snail during breeding season. As other terrestrial animals, including insects and mammals use airborne pheromones, the mucus trail will also be analysed for volatile chemicals. Initial analysis has already identified two promising chemicals.

SLIME ENTRAPMENT

Identification of an attractant pheromone may be useful in the control of snails by enticing them to a trap, similar to the lure-and-kill technique used in pheromonal insect control. Alternatively, an attractant could be incorporated to the snail baits that would make the baits more likely to be consumed by snails. Given the propensity for snails to cover a significant area of ground during the active season, the mucus trail will also be analysed for microbial components to establish whether snails play a role in the transmission of crop disease. Preliminary analysis has identified several fungal species of agricultural significance in the mucus trails. □

GRDC Code USU1903-001
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Photo: Scott Cummins, University of the Sunshine Coast

Kate Ballard on the hunt for snails and their slime in the field, Yorke Peninsula, SA.

Natural enemies to be enlisted against green peach aphid

Photo: Wei Xu, Murdoch University

Ladybird beetles, such as these two *Coelophora inaequalis*, use semiochemicals to find their prey.

Photo: Wei Xu, Murdoch University

Andrew Phillips (right) with Dr Dustin Severtson, his co-supervisor from the DPIRD, sweep netting a canola crop and checking smart traps for aphids and other pests at Northam, WA.

By Andrew Phillips

KEY POINTS

- Alternative methods of control need to be sought for the green peach aphid as the pest rapidly develops insecticide resistance
- Semiochemicals produced by natural predators may have potential as a biological control agent

■ Chemical control of the green peach aphid (*Myzus persicae* – GPA) is still the main tool for growers, but options are diminishing. Globally, the aphid has developed resistance to more pesticides than any other pest species. In WA, sulfoxaflor (Transform®) and carbamate pirimicarb (for example Pirimor®) are the active ingredients registered for use on GPA in canola. GPA already has resistance to carbamate and there is evidence that it is developing resistance to sulfoxaflor.

One option is biological control, using predators, parasites and pathogens to control a pest population. However, the use of biological control for aphids has not been very successful, generally due to aphids reproducing too quickly for their natural enemies to keep up and natural enemies arriving too late in the season.

However, as GPA continues to develop insecticide resistance faster than new insecticides can be developed, time is up.

SEEKING INNOVATIVE APPROACHES

So how can we make biological control of aphids in broadacre crops, such as canola, viable? One potential is semiochemicals. These are organic chemicals, such as pheromones, that convey a message from one organism to another. There are two potential uses of semiochemicals in the field, neither of which excludes the other. The first is to use them as lures – to bring natural enemies into the field earlier so they have more impact on the aphid population.

This would likely need to be coupled with some form of artificial diet or supplementary crop, to provide food for the natural enemies. Most natural enemies in their adult stages are mobile and capable of leaving the crop if there is insufficient food.

The other method of biological control is to raise beneficial insects in another location and expose them to the semiochemical, then mass-release them. In this scenario, the semiochemicals are used to 'prime' the insects, so that they learn to associate the chemicals of the crop they are being released into with prey. Insects are known to be able to learn and there is evidence that they are attracted to the chemicals that are present when they hatch or pupate. By exposing newly emerging insects to chemicals associated with the target crop, we could help them spend longer foraging in the field, consuming aphids and hopefully suppressing aphid populations.

BLUE-SKY PROJECT

To apply either of these methods, though, knowledge of the chemicals that natural enemies find attractive is needed. This GRDC-invested PhD project, supervised by Dr Wei Xu and Dr Stephen Milroy from Murdoch University and Dr Dustin Severtson from the WA Department of Primary Industries and Regional Development (DPIRD), began in 2019. The project aims to identify the natural enemies, such as ladybird beetles (*Coccinella transversalis* and *Harmonia conformis*) and parasitic wasps (*Diaeretiella rapae*) present in south-west WA canola fields and the chemicals released by aphids and aphid-infested canola. This will be followed by behavioural and electrophysiological experiments to determine which of these chemicals can potentially be used to help control aphid populations in canola fields. □

GRDC Code UMU2001-003

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Parasitoid wasps with a taste for aphids

By Samantha Ward

KEY POINTS

- **Biocontrols are important components of integrated pest management (IPM)**
- **Knowledge of the distribution of parasitoid wasps and their capacity for biological control is important to inform IPM strategies that conserve them**

Canola can be attacked by at least 30 species of invertebrate pests in Australia. Synthetic pesticides have been the main control agent and this single-technology approach is likely to increase the risk of pest resistance and also harm pests' natural enemies. However, researchers have discovered a tiny parasitoid wasp at work in Australian canola crops that is showing potential as an effective biocontrol.

Like parasites, parasitoids live at the expense of another organism (the host); however, parasitoids kill the host to complete their development. Aphid parasitoids are tiny wasps found in the insect order Hymenoptera (which includes wasps, bees and ants). These wasps require an aphid host to complete their larval development, before bursting out of the 'mummy' (the altered body form of the aphid host).

PARASITOID WASPS AND APHIDS

With GRDC investment, a PhD project at the University of Melbourne focused on parasitoid wasps associated with aphids.

It aimed to understand population dynamics through the growing season, parasitoid diversity, abundance and distribution across grain production landscapes, and host associations. The aim was to determine how important parasitoids are as natural enemies of grain aphids in Australia.

One parasitoid wasp – the cabbage aphid parasitoid wasp (*Diaeretiella rapae*) – dominated paddock surveys in 2016–19. This species controls many aphids but has a strong preference for brassica aphids. In the surveys it was found less at the edges of paddocks than within paddocks, and it was more common in canola than in wheat (Figure 1).

Due to the abundance of green peach aphids (GPA), variation between observed and actual rates of parasitism was investigated in canola in NSW, SA, Victoria and WA in 2019.

Actual parasitism rates (in-field mummy counts) were determined by the number of wasps reared within the laboratory from all collected aphids/mummies. In-paddock counts can miss aphids that are recently parasitised, as the mummies are not visible until a few days after wasp egg-laying. Actual parasitism was 237 per cent more than what was observed in the field in most states, but four-fold in SA. This makes it clear that mummy counts alone do not provide a clear indication of actual parasitism.

The importance of wasp species as a biological control can vary depending on the crop. *Diaeretiella rapae*, although the dominant parasitoid found in the field, is not yet available for commercial application. However, enhancing natural populations of wasps by accepting some aphids in the crop may help aphid control. When aphid mummies are observed, it is likely that there is much higher actual parasitism happening and management decisions (for example, whether to spray) should take this into account, as well as the number of aphids.

Although wasps may not be observed early in the season, numbers can build later, along with increased rates of parasitism. This means that *Diaeretiella rapae* can also help control cabbage aphids later in crop development, when there is risk of aphid damage during flowering and podding. □

GRDC Code CSP1501-002 (CSE00059)

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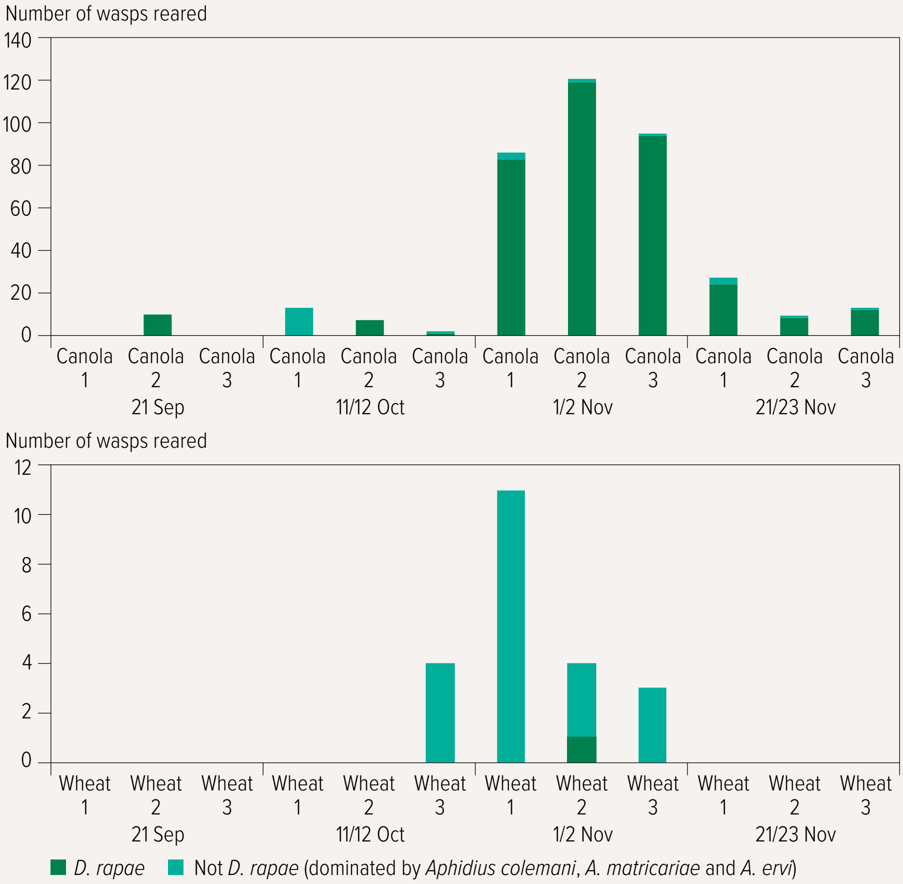
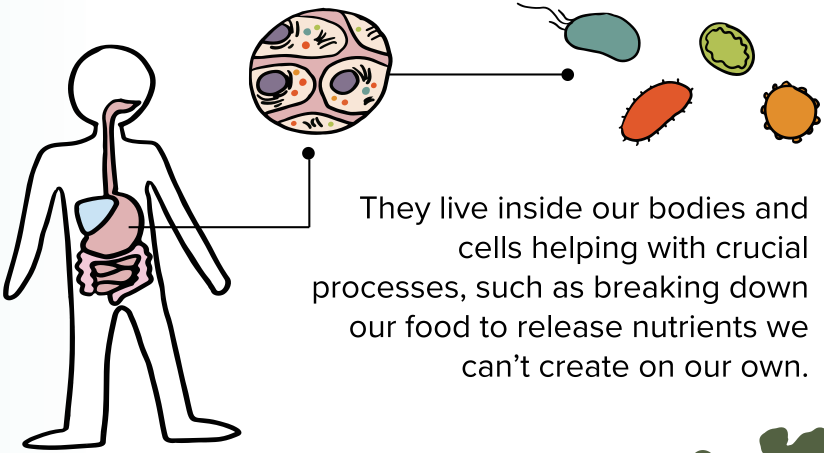
Figure 1: Comparison of *Diaeretiella rapae* numbers reared from aphids compared to other wasps (total of nine species) in three canola paddocks and three wheat paddocks repeatedly sampled in 2018.



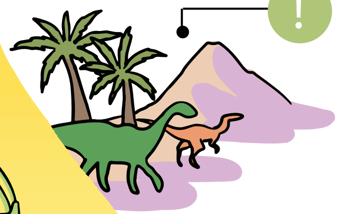
Source: Samantha Ward

What are endosymbionts?

Inside most creatures are tiny microorganisms called **symbionts**.

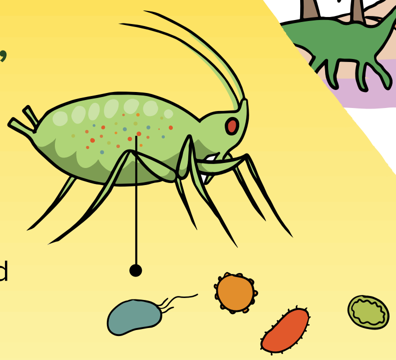


They live inside our bodies and cells helping with crucial processes, such as breaking down our food to release nutrients we can't create on our own.



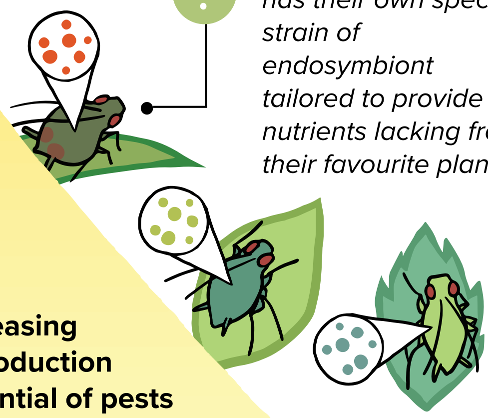
Insect-endosymbiont relationships began over 200 million years ago!

Insects have these too! We call them 'endosymbionts'



Endosymbionts provide insects with nutrients that they can't get from their diet.

But what is good for the insect can be bad for the farmer. Endosymbionts can make our jobs trickier by:



Each aphid species has their own special strain of endosymbiont tailored to provide nutrients lacking from their favourite plant.

- **increasing virus transmission**
- **protecting pests from predation**
- **protecting pests from insecticides**
- **increasing reproduction potential of pests**

Is it possible to manipulate insect pest endosymbionts to protect crops? Maybe!

Increasingly, research suggests that manipulating endosymbionts could allow us to reduce the impact of harmful pest insects.

Endosymbionts that block virus transmission by mosquitoes are being used to control the spread of Dengue fever!

So what's next?

The Australian Grains Pest Innovation Program (AGPIP) is investigating ways we can manipulate symbionts to improve pest management in grains.

Find out more at
https://blogs.unimelb.edu.au/pearg/

AGPIP is a collaboration between The University of Melbourne Pest and Environmental Adaptation Research Group and cesar, and a co-investment between The University of Melbourne and the Grains Research and Development Coorporation

Illustrations by Dr Elia Pirtle, **cesar**

cesar

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