KIT 3.4

Develop and implement management options to minimise the cost of effectively and sustainably managing vertebrate and invertebrate pests

Impact	**Growers have access to a diverse range of integrated management options to reduce the impact of priority pests in grain crops and stored grain.**
Summary	• Growers have access to options to effectively minimise the impact of pests on farming systems and profitability. • Growers utilise integrated management strategies to maintain the effectiveness of pest control options.

OVERVIEW

Vertebrate and invertebrate pests are significant constraints to the production of profitable grain crops and their storage in Australian farming systems. Grains pests can typically damage crop production in four main ways:

- Economic loss from direct feeding
- Quality downgrading
- Delayed or sub-optimal establishment
- Transmission of vector borne viruses.

Grain growers continue to face significant losses from invertebrate pests, which are responsible for estimated annual losses of well over $360 million in key grains crops[1]. The greatest losses are attributable to redlegged earth mite, budworms, blue oat mite, Lucerne flea and locusts, followed by slugs, aphids, snails, armyworms and other mites. This losses estimate is limited to 'feeding damage' and does not include losses from 'quality' downgrading due to pest damage or other losses such as diseases or viruses transferred by insects as vectors. In addition, invertebrate pests of stored grain have the potential to cause considerable reduction in grain quality as well as create market access issues.

Vertebrate pests associated with production losses in the grains industry include mice, rabbits, feral pigs, kangaroos, emus, wombats and birds. Mice are the major vertebrate pest impacting Australian grain cropping systems, increasing in number to plague proportions under favourable conditions.

The management of pests in an effective, efficient and sustainable manner is vital to ensure ongoing profitable farming systems. Pesticides are often a key component of control strategies for grain pests. Global regulatory pressures, increasing incidence of insecticide resistance and changes in market requirements relating to the acceptance of the use of pesticides pose considerable challenges for the future of pest management in Australian grain crops.

Achieving sustainable pest management practices involves creating and implementing systems-level strategies that reduce the reliance on broad-spectrum chemistry, minimise the evolution of insecticide resistance, and lead to improved environmental, social and financial outcomes for Australian grain growers. While sustainable or integrated pest management (IPM) approaches have been adopted successfully in some horticultural industries and the cotton industry, adoption has been slower in the grains industry. Adoption of IPM in the grains industry is hampered by the availability and reliance on effective, low cost chemical pest control options. The complexities of grain growing systems necessitate understanding and interpretation of intricate factors including the biology and ecology of a pest, the interactions between crop growth and pests, and between pests and their natural enemies. While progress has been made in understanding the biology and ecology of key grains pests in Australia, a greater depth of understanding is required to pre-empt and reduce pest outbreaks, monitor pests more effectively and facilitate holistic, whole farm, systems approaches to pest management into the future.

[1] Murray, D. A. H., Clarke, M. B., & Ronning, D. A. (2013). The current and potential costs of invertebrate pests in Australia. GRDC Project Code AEP00001. Grains Research & Development Corporation, Kingston, Australia.

Key Investment Target (KIT) 3.4 aims to develop knowledge, novel tools and technologies to reduce the impact of the highest priority pests in farming systems and on grain production with the following scopes:

1. Understanding the distribution and impact of pests in crops and stored grain
2. Understanding the biology and ecology of priority pests and their predators
3. Tools and technologies to manage pests
4. Integrating technologies and knowledge to make informed pest management decisions in farming systems.

For the purposes of this document, the term 'natural enemy' includes a 'predator', 'parasitoid' and 'pathogen' of grain pests. These can be native or introduced and occur in the environment or be applied preventively.

FUTURE RD&E FOCUS

SCOPE – Understanding of the distribution and impact of pests in crops and stored grain

The current and potential distributions and impacts of pests are known and are used to determine future GRDC investment priorities.

Surveillance and diagnostic capacity are fundamental elements to the development of cost-effective pest management strategies. The key objectives of effective surveillance and diagnostics are to deliver:

- Actionable intelligence that can lead to enhanced profitable and sustainable pest management strategies
- A basis for prioritisation of RD&E that focuses effort on reducing the costs and impact of the most economically important pests
- A mechanism for monitoring pests across the landscape to identify emerging threats
- Characterisation of the changing nature of pest populations (e.g. insecticide resistance and shifts in pest complexes) to inform short and long-term pest management
- Information needed to plan and implement optimal management of biosecurity risks through preparedness and planning activities to safeguard grower profitability
- Information that can demonstrate pest area freedom to support market access and/or create market differentiation opportunities.

Improved surveillance will facilitate industry's ability to demonstrate pest area freedom; analyse inter-seasonal and national trends; monitor the impact of RD&E efforts; and predict future pest outbreaks. There is also an opportunity to enhance the value of surveillance data that is collected through better data management and coordination of activities.

GRDC will consider investing in the improvement of pest surveillance and diagnostics, and in understanding the impact of future climates and cropping systems on pest management. This interdisciplinary research will demand combined expertise in pest science, crop science, engineering and data science for the design and implementation of low-cost, low-power technology to help reduce the extent of quantitative and qualitative crop losses attributable to the most significant grains pests.

Investment Outcome 3.4.1 – Growers and researchers know the current and potential impacts of priority pests.

Future RD&E effort will be focused on those pests with the greatest potential impact (priority pests) on the enduring profitability of Australian grain growers. New and emerging pests will be prioritised based on their potential impact to industry. Sound estimates of yield and economic losses caused by pests are required to inform the ongoing prioritisation process. For some priority grains pests, further work is warranted to determine their current and potential distributions, and quantify their economic impacts on different crop types, in different farming systems and growing region, and under future farming systems and climate scenarios. In addition, further understanding is needed on the impact of stored grain pests on grain quality and market access (constraints and opportunities), and in turn on current and future profitability of grain growers.

Investment Outcome 3.4.2 – Growers use reliable, accurate tools and technologies to identify and quantify pests and to determine the spatial and temporal distributions of pests in farming systems.

Growers require information on the spatial and temporal distribution of pests over both the short- and long-term and at both paddock and regional scales. This information is required so that growers can optimally plan for and manage pests.

Surveillance activities should be designed and coordinated across regions to optimise the management of data. Optimised data management will enable the analysis of data across regions and over time, improve the ability to forecast outbreaks, and assist in planning and informing profitable decision making. Enhanced surveillance methodology and data management may require new tools and technologies, such as remote sensing and in-field diagnostics. Additionally, there is a requirement for the development and implementation of robust strategies that facilitate rapid adoption of existing, novel and practical pest identification tools.

Investment Outcome 3.4.3 – Growers understand the impacts of pest contamination of grain.

The competitive position of the Australian grains industry in international markets depends on it maintaining or enhancing its reputation as a reliable supplier of high-quality grain, free of pest contamination (live or dead, whole or parts) and damage, and with very low or zero chemical residues. Effective pest management decisions at all phases of grain production, from in the field through to storage, can minimise pest contamination of grain and therefore maximise grain quality and the marketability of grain. It is vital for growers to understand the impacts of pest contamination of grain on market access and farm profitability. It is also important for growers to understand what potential strategies are available to them to minimise the impact of this contamination on grain quality and marketability. GRDC will consider investing in research focused on understanding and minimising the impacts of pest grain damage and contamination, from in-field through to harvest and in storage.

SCOPE – Understanding of the biology and ecology of priority pests and their predators

Knowledge of the life cycles of pests and their predators under current and future farming systems is improved to inform the development of optimum pest management tactics and strategies.

The implementation of sound pest management practices requires understanding of the biology and ecology of priority pests and their predators within Australian farming systems. The pest and predator complexes encountered within Australian farming systems can readily change in abundance and composition through the seasons and under different environmental conditions.

The invertebrate pests affecting grain production which have received the most extensive biological and ecological research focus are mites, Australian plague locusts, native budworms, aphids, diamondback moths and snails. Despite some pest groups being well studied, there is still relatively little known about the factors that influence species abundance and the drivers of sporadic pest outbreaks in grain crops. Other knowledge gaps include understanding of the physiology, taxonomy, plant host use, feeding behaviours, diapause patterns and chemical sensitivities of many pest species.

Agronomic practices such as crop rotations, stubble management and tillage can influence the dynamics of pests and their predators, leading to changes in pest incidence and severity. Much of the previous grains pests related research on which current management recommendations are based was conducted under farming systems where tillage events were common. Consequently, pest management research may need to be revisited to ensure the availability of robust foundational knowledge on pest and predator behaviour under contemporary farming systems.

Natural enemies (predators and parasitoids) can make significant contributions to the suppression of insect pest populations in many cropping systems. Australian research on natural enemies of crop pests has included investigations into the behaviour, population dynamics, taxonomy and biology of parasitic wasps, spiders, carabid beetles, lacewings and lady beetles in various agricultural systems. Natural enemies are an important component of pest management systems in cotton and horticultural agroecosystems. This is not the case in grain production systems as less is known about natural enemies' preferences for pests in grains systems. Given the diversity of natural enemies in Australia, a greater understanding of their ecology, host specificity, distribution and role in grain growing situations is needed. Importantly, the potential for natural enemy species to reduce the impact of grains pests, particularly when pesticides are used, has not been quantified in the farming systems context. Generating robust field data in this area is challenging because there is large variability in the level of control provided by natural enemies, both spatially and temporally, the reasons for which are poorly understood. A further complication is that some species, such as the European earwig, can be described as a natural enemy in some agricultural situations but can switch unpredictably to a pest by feeding on crop seedlings rather than other invertebrates or stubble.

The development of sustainable pest management practices requires a thorough understanding of agricultural management in the landscape (e.g. crop spatial arrangement and extent, and rotational sequences) and how farming practices might influence crop-pest interactions. GRDC will consider research focussed on better understanding, through novel and innovative approaches, the complexity of interactions between grain crops, pests, and their predators. GRDC is likely to continue to invest in furthering industry's knowledge of pest biology and ecology under current and future growing conditions and farming systems. A balanced and collaborative approach to future RD&E investment will address existing knowledge gaps, anticipate future pest issues and encourage innovative pest management approaches to ensure delivery of benefits to Australian grain growers.

Investment Outcome 3.4.4 – Growers and researchers understand the life cycles, host interactions, dispersal, survival and distribution of pests and their predators, to better inform pest management decisions.

Deployment of effective on-farm pest management practices depends largely on the understanding of the dynamics of pests and their predators under current and future crop growing conditions. GRDC will consider research aimed at assisting the design of improved and novel pest management strategies and technologies to better understand pest and predator biology, including fitness under current and future climatic conditions.

GRDC will consider future RD&E investment aimed to deliver new knowledge and understanding including but not limited to the:

- Drivers of pest evolution and adaptation
- Underlying mechanisms of crop-pest interactions both at the molecular and cellular levels
- Host range of introduced and endemic pest predators and natural enemies and their contribution to insect pest suppression in the diverse grain agroecological systems in Australia
- Quantitative influence of natural enemies on pests at a whole-field scale (threshold predator/prey ratios)
- Spatial patterns, including dispersal, of pests and their predators including factors that lead to pest outbreaks
- Survival, persistence and resource requirements of naturally occurring natural enemies under different grain cropping systems and pest management regimes
- Potential of artificially reared pest predators or natural enemies for biocontrol in grain crops.

Investment Outcome 3.4.5 – Growers monitor and have knowledge of changes in pest impacts, host interactions, pesticide resistance and the influence of climate variability on pest dynamics.

Some general baseline pest monitoring activities occur throughout Australia that inform industry of pest incidence and pressure across the landscape. However, most of these are passive systems that rely on reports from growers, agronomists and research groups. There is a need for a more active, collaborative, integrated approach to collecting pest monitoring data at a local, regional and national level. There may also be opportunities to automate pest monitoring, reduce inefficiencies and deliver timely reporting to industry. Predictive models for the impact of future climates and cropping systems on pest abundance and damage potential may enhance long-term grower preparedness. Successful integration of biology and ecology knowledge with other data for reliable prediction models can be improved.

Early detection of reduced sensitivity or resistance to insecticides in pest populations is important. Early detection allows time for changes to management practices to be identified and implemented. This in turn would mitigate potential yield losses due to insecticide failure, in addition to preventing resistant pest populations from becoming dominant. Interactive tools that show the distribution, frequency and incidence of insecticide resistance across regions may be of considerable value in this area. Effective and efficient in-field monitoring tools are key to fighting insecticide resistance and are therefore will be an important consideration for future RD&E investment.

SCOPE – Development of tools, tactics and technologies for strategic pest management

Improved genetic, physical, cultural, chemical and biological tools and technologies for pest management are developed.

Cultural control methods for grain production pests such as conservation of natural enemies, manipulating time of sowing, crop destruction, crop rotation, weed management and cultivation can be useful for the control of some invertebrate pests. However, some traditional interventions are no longer compatible with modern conservation farming principles, such as

direct drilling, that have been widely adopted by Australian grain growers. A greater understanding of the relationship of stubble management and emerging pest outbreaks will assist growers to use targeted physical and cultural tools to disrupt pest life cycles in an integrated pest management approach. Consideration of the impacts of fundamental crop management practices (including crop choice, sowing methods, seeding rates, crop rotations, weed control and tillage) on managing pest populations is crucial for growers in farm decision making and planning. Systems-level approaches may be beneficial to generate information on dynamic economic thresholds, pest responses to climate variability, and the long-terms impacts of management practices on pests and natural enemies.

Unlike diseases, for which resistant crop varieties have been a valuable component of disease management strategies in Australia, the relative level of development and deployment of crop varieties with host plant resistance against invertebrates has been negligible (apart from aphid-resistant lupins and sorghum midge-resistant grain sorghum). While novel genetic approaches to pest control hold promise for the future, their development and effective deployment for managing pests in grain landscapes will be dependent upon a greater understanding of pest biology and ecology.

For most grains industry pests, pesticide intervention remains the primary control measure. Pesticides are often applied as a pre-emptive risk reduction or 'insurance policy'. Beside the input cost, this practice has the potential to exacerbate the development of insecticide resistance, which threatens the long-term viability of pesticide-based control options. Improving understanding of how management strategies that use existing insecticides and modes of action impact on the level of efficacy and development of insecticide resistance will minimise the risk of crop losses. Furthermore, some important pesticide groups are under regulatory threat due to human health and environmental concerns. Ensuring grain growers can continue to effectively control damaging pests may require the development of new chemical and non-chemical alternatives, including biopesticides. Although some biologically based products are being deployed overseas and in other high value industries to manage crop pests, their use and the value proposition they provide for Australian grain growing systems has not been widely evaluated nor demonstrated.

Currently, growers have limited access to information on timely and actionable seasonal risk pest management options that optimise input costs and reduce the incidence of pests. Additionally, there are few effective pest monitoring tools available to growers. Robust sampling and monitoring information is of critical importance for the adoption of pest economic thresholds. Industry could benefit from decision support tools and systematic pest surveillance and monitoring to warn of endemic/emerging and exotic pest issues before significant crop losses occur. The development and deployment of new digital technologies may provide opportunities to automate pest monitoring, improve efficiencies and provide in-field support for biotic threat identification, data collection, and/or reporting. Understanding the specific factors that lead to pest outbreaks is required to predict where these will occur in the future. While some of these factors are known, the information has not been integrated into predictive models that may aid in decision making and adoption of integrated management practices by growers. Predictive models for pest outbreaks, validated in the field and across multiple regions, may enable growers to predict risk to Australian grain crops.

As insecticide resistance and regulatory concerns increase, there will be a growing need to rely more heavily on biologically based control methods for grain pests in Australia. Information about the impacts of natural enemies on pests (including host specificity for parasitoids), their susceptibility to insecticide applications and the resources they require to survive between crops would be important in facilitating the integration of biological control with chemical control options. Tactics to enhance the impact of natural enemies in Australian grain systems are required so that they can be incorporated with confidence into pest control strategies.

It is expected that the commercial drivers will ensure the ongoing development of new, low impact, targeted insecticides with little or no GRDC investment. GRDC may consider becoming involved in insecticide development where market failure occurs, or to assist in improving the timeliness of delivery of new insecticide classes and modes of action to Australia.

GRDC will continue to consider investing in the development of knowledge and tools that assist grain growers manage important pests of grain crops. The targets for future RD&E investment are likely to include the following:

Investment Outcome 3.4.6 – Growers accurately and rapidly detect pests in crops and stored grain.

Maintenance and enhancement of grain grower capacity to identify and diagnose high priority endemic and exotic pests, utilising appropriate laboratory and in-field techniques, is important. Early detection and management of endemic

pests would be enabled by the provision and adoption of conventional and new monitoring technologies and diagnostic tools by grain growers and their advisers. The development of automated tools for early detection, quantification and identification of pests on-farm would enable grain growers to implement cost-effective and timely management action in the paddock and within grain storages. Efficient monitoring techniques for pests and their natural enemies would also facilitate the establishment of links between in-field pest numbers, crop damage and yield loss. In turn, this information could contribute to the development of economic thresholds. Dynamic on-farm models would facilitate informed intervention decisions that could lead to improved whole farm profitability. GRDC will consider future RD&E investment aimed at providing grain growers with practical tools and technologies to identify and quantify pests on-farm.

Investment Outcome 3.4.7 – Growers have access to diverse genetic, physical, cultural, chemical and biological approaches for pest management in crops and stored grain.

A key to the development and implementation of effective long-term, sustainable pest management strategies is providing grain growers with access to a diverse set of control options and tools. The focus for future RD&E may include the development of integrated approaches that use genetic, physical, cultural, chemical and biological tools and technologies to reduce the impact of pests while enhancing their natural enemies. The accelerated discovery, characterisation and deployment of new pest control measures could be achieved through:

- Understanding how to conserve, manage and improve the efficacy of natural enemies and how best to incorporate these into practical decision-making in different cropping systems
- Improved strategic use of physical and cultural control practices, including tillage and stubble management, and improved implementation of crop rotations, crop variety selection, sowing date, planting density, harvest date, and understanding of crop compensatory capacity to provide optimal pest control outcomes without compromising profitability
- Understanding the impact of major agronomic practices (especially insecticide application) on (1) non-target pest species, to avoid flare-ups, (2) natural enemies and (3) farm profitability
- Identifying opportunities to exploit plant genetic characteristics (including plant pest tolerance and competitiveness) to manage pests
- Understanding the genetic mechanisms of insecticide resistance, to monitor populations for resistance efficiently, minimise control failures and inform effective resistance management strategies
- Development of novel pesticide chemistries and non-chemical pest management approaches which may include engineering and biological solutions (such as biopesticides) and innovative molecular technologies and genetic tools for pest management in Australian grains
- Improved physical, cultural, chemical and biological options for maintaining quality and hygiene of stored grain
- Identifying opportunities to co-invest with the agrochemical industry where there is market failure, or to increase the timeliness of delivery of new insecticide classes and modes of action to Australia.

GRDC will consider partnering with entities that have proven research, freedom-to-operate and path-to-market expertise to facilitate the discovery and delivery of new chemistries and approaches, both traditional and novel. Some of these approaches may require fostering collaboration with non-traditional Australian and international investment partners where appropriate.

Investment Outcome 3.4.8 – Growers have access to improved novel technologies and approaches for pest management, including solutions that impact at the paddock, farm and landscape level.

Integrating information on the biology of pests and their natural enemies with information on factors that cause populations of both pests and enemies to increase will allow for the development of novel technologies and approaches to manage grains pests. Improved pest monitoring, detection and identification could be augmented by the development of:

- Precision application technologies with superior systems of delivery for crop protection solutions (e.g. targeted spray or bait application, deployment of biological control agents, attract and kill technologies)
- Precision removal and/or separation technologies that target pest contaminants of grain (e.g. sensor and engineering solutions to exclude or separate contaminants at harvest or along the supply chain).

GRDC may partner with relevant technology industry leaders to develop these novel approaches.

SCOPE – Integration of new tools, technologies and knowledge to make informed pest management decisions in the whole-of-farming-system context.

Pest management strategies are applied, on farm and across the landscape, to optimise growers' long-term profitability.

Successful in-season management of pests relies on growers understanding:

- The pest complexes present, their abundance, and their potential to cause economic losses
- The likelihood of environmental conditions occurring that affect pest reproduction, spread and population growth in a positive or negative way
- What cost-effective and practical options are available to manage pests.

The effectiveness of these tactical decisions could be further enhanced by knowledge of how pests and their predators persist between seasons and across the rotation using the green bridge and non-crop areas. Implementation of diverse IPM approaches offers the best options for managing grain pests in a sustainable manner. While previous GRDC investments have examined strategies for effective IPM, research has shown that it is challenging to integrate this knowledge into wider farming system decision making, and therefore pesticides continue to be the mainstay of pest management. The low costs associated with the application of some insecticide groups commonly used in grain crops (such as carbamates, organophosphates and pyrethroids) has seen their adoption over large areas. This has contributed to the evolution of insecticide resistance in several grain pests in Australia, such as redlegged earth mite, green peach aphid, diamondback moth and cotton bollworm. Similarly, the reliance on phosphine as a fumigant for stored grain has led to resistance to this chemical being recorded in all major stored grain pest species in Australia. Grain growers find themselves in a vulnerable position of high reliance on only a few chemical groups that may lose their efficacy due to resistance development or regulatory changes that restrict or cease their use. However, opportunities exist for Australian grain growers to reduce pesticide inputs in some seasons without risking yield loss by employing diverse IPM strategies.

Preservation of existing chemistries requires the adoption of robust pest management practices that are practical, effective and economical. Overall, the integration of new tools, technologies and knowledge will need to be based on methods that interrupt the life cycle, interfere with movement, or otherwise limit the numbers of pests or damage from those pests.

Effective extension will be required for grain growers to adopt new methods particularly the adoption of IPM in the whole-of-farming system context. GRDC will consider future RD&E investment aimed at the integration of technologies and knowledge so growers can make informed decisions to manage ongoing insecticide resistance evolution in Australian farming systems.

Investment Outcome 3.4.9 – Growers understand pest and predator dynamics and incorporate surveillance, seasonal forecasting and knowledge of landscape impacts into their management decisions.

The target for GRDC investment in this space will be to move pest management decisions from being responsive to being timely, scientifically informed and evidence based, incorporating robust field intelligence and predictive modelling. An RD&E priority may be the development of dynamic pest risk/decision support tools incorporating knowledge of pest and predator dynamics, surveillance data and seasonal forecasting. Agronomic models that incorporate knowledge on grains pest damage under different pest management strategies would be expected to also help in optimising grain grower profitability. A thorough understanding of the interactions between pests and natural enemies within the landscape context could provide new options for pest management. Understanding the effects of chemical application and other management practices on natural enemies, and the implications of these on other, non-target pest species within the landscape would be important considerations. Understanding the impact of future cropping systems and climate scenarios on pest distributions and outbreaks, as well as the potential effectiveness of natural enemies within the landscape, could allow for more cost-effective pest management approaches.

Investment Outcome 3.4.10 – Growers make informed decisions using knowledge of the effects of rotations, pest thresholds and farming system changes.

Changes in cropping patterns, pesticide use, climate and farming systems are likely contributors to the shifting complex of pests impacting the Australian grains industry. Reliable and robust economic thresholds for key pests will underpin informed on-farm decision making. The aim of this investment outcome is that growers will be able to understand and have confidence in the economics of employing dynamic pest thresholds in their farm decision making, including having the ability to adequately assess the risk of losses caused by pests, including plant compensation to pest damage.

Investment Outcome 3.4.11 – Growers minimise the development of pesticide resistance by using diverse and practical pest management strategies.

The impact of pesticide resistance on the Australian grains industry could be mitigated by the appropriate deployment of existing chemistries in an IPM approach that is practical and easily adopted by growers. The aim for the investment outcome is that best practice pest management would be underpinned by knowledge on the spatial distribution of resistance and an understanding of the mechanisms that create resistance. It is expected that resistance management strategies (RMS) for key grains pests will continue to be developed, optimised and adopted with high confidence by industry. The RMS will aim to encompass the cropping system and pest complex and would incorporate a range of control strategies including non-chemical methods and softer or more selective chemical options.