Final report

Improved management of redlegged earth mite – leveraging GRDC investment

Project code: P.PSH.1283

Prepared by: Luis Mata, Aston Arthur and James Maino
Cesar Australia

Date published: 11 June 2024

PUBLISHED BY
Meat and Livestock Australia Limited
PO Box 1961
NORTH SYDNEY NSW 2059

This is an MLA Donor Company funded project.

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government and contributions from the Australian Meat Processor Corporation to support the research and development detailed in this publication.

This publication is published by Meat & Livestock Australia Limited ABN 39 081 678 364 (MLA). Care is taken to ensure the accuracy of the information contained in this publication. However MLA cannot accept responsibility for the accuracy or completeness of the information or opinions contained in the publication. You should make your own enquiries before making decisions concerning your interests. Reproduction in whole or in part of this publication is prohibited without prior written consent of MLA.

Abstract

The redlegged earth mite (RLEM) is a widespread pasture pest that significantly affects the profitability of pasture-based industries. Insecticides are the dominant control strategy for RLEM but increasing resistance issues requires new management options. In this project we aimed to (1) understand the current extent of resistance in pastures; (2) improve the precision of control by developing spray and egg hatch timing tools; (3) identify new synthetic insecticide options; and (4) benchmark current knowledge and develop a Producer Demonstration Site (PDS). To achieve this, we screened over 480 RLEM populations, including 49 in pastures, across NSW, SA, Victoria and Western Australia for resistance through phenotypic discriminating bioassays and/or genetic markers; developed a web tool that predicts RLEM egg hatch dates in autumn; investigated the influence of climate change on the effectiveness of TIMERITE®; tested six novel modes of action and two biological products in microcosm trials on pasture, with two products tested in field trials; investigated the knowledge, practices and attitudes of growers and advisors relating to RLEM insecticide resistance management through social benchmarking; and planned and delivered an ample range of extension activities to support graziers and advisors in adopting and testing the tools, findings, and recommendations derived from the project.

We found a substantial increase in detections of resistance to organophosphate and synthetic pyrethroid in RLEM populations in eastern Australia, particularly in SA. Our testing of novel modes of action and biological products under microcosm and bioassay trials ruled out many products as having potential for RLEM control, with two products showing high efficacy. Field testing of these two products, however, did not show the same level of efficacy. We found that climatic variables enhance diapause prediction and improve the accuracy of predicting diapause onset in RLEM, compared to using only daylength and growing season length as in the original TIMERITE®. Similarly, we found that the hatch timing tool successfully predicts the hatch timing of RLEM. Our benchmarking study provided insights into the spray frequency of different chemical groups used by producers and recommended by advisors, with producers and advisors exhibiting distinct risk attitudes. We worked closely with MLA to produce extension and communication outputs, which have been showcased through the project's associated PDS 'Less Mites, More Feed'.

New knowledge gained through the project will be fed into the new version of the RLEM Resistance Management Strategy, ensuring it provides the best practice recommendations for RLEM control. The hatch timing tool will increase the monitoring precision of RLEM and thus minimise pest risk. The updated TIMERITE® offers significant benefits to the red meat industry by minimising RLEM impacts, improving pasture productivity and quality, reducing pesticide use and input costs, and enabling adaptation to climate change. Insights from the social benchmarking study are playing a key role in informing communication and extension outputs. The PDS project is being conducted in collaboration with 15 core producers and 93 observer producers. Extension outputs are benefiting the industry by increasing awareness about the lifecycles of pest mites and highlighting the longer-term implications of resistance.

Our findings highlight how future management of RLEM should aim to reduce the use of chemicals to limit selection pressure and decrease the risk of resistance evolution. Ongoing resistance surveillance to monitor the distribution and levels of field resistance will be crucial to identify emerging resistance issues. In addition to OPs and SPs, it will be critical to explore any arising potential resistance to neonicotinoids in RLEM. Similarly, our results point out the need to continue to explore novel modes of action and biological products. It will be critical to ensure that the Resistance Management Strategy is continually updated with the latest research and best management practice recommendations, and that it is extensively promoted to increase awareness and adoption of its recommendations by meat and livestock growers and advisors. Facilitating the extension of research findings holds a crucial role in advancing industry knowledge and fostering adoption in future initiatives addressing RLEM resistance and control. Finally, we recommend that MLA continues to work in collaboration with other industries impacted by RLEM to improve the management of RLEM and reduce its significant current economic impact.

Executive summary

Background

The redlegged earth mite (RLEM) is one of the most important pest of pastures, affecting the production and profitability of red meat producers in southern Australia. Insecticides are currently the most effective and widely used control method against RLEM but increasing resistance to synthetic pyrethroids (SPs) and organophosphates (OPs) requires new management options. There is a critical need to understand vulnerabilities in the RLEM lifecycle at diapause and hatching to improve and develop pest forecasting tools for livestock producers, which will allow them to respond to increasingly variable climatic conditions.

Overarching project outcomes include enhanced farm profitability through improved control strategies for RLEM, increased producer confidence in RLEM seasonal risk, impact potential, and appropriate control options that will maintain the long-term effectiveness of current chemical control options through resistance management strategies. Importantly, this investment was leveraged against existing multi-year GRDC ($2.6M over 5 years) and AgriFutures ($88.9K over 3 years) investments, delivering a high return for red meat producers.

Objectives

The specific objectives of the project were to (1) conduct targeted field collections of RLEM populations across eastern Australian red meat production regions to understand the current extent of resistance issues and control failures; (2) deliver decision support tools through validating a web tool predicting RLEM egg hatch and updating TIMERITE® diapause tool based on current regional environmental conditions in red meat production systems; (3) identify new synthetic insecticide options against RLEM and explore the potential of biological molecules through lab trials and pasture trials; (4) expand grains industry focused social research on current knowledge, attitudes and practices into pasture-based industries; and (5) work with producer groups and the Producer Demonstration Site (PDS) team at MLA to explore and design a project to support producers in testing research-led management advice and share findings within and outside of the group.

Methodology

- RLEM resistance screening was undertaken in 2021-23 across southern Australia (NSW, SA, Vic and WA). Over 480 RLEM populations were screened for resistance through phenotypic discriminating bioassays and/or genetic markers. Of these, 49 populations were screened as part of this project, which supported the targeted screening of pasture sites from red meat production regions.
- A previous study on predicting hatch dates from regional temperature and rainfall conditions was extended to an easy-to-use web interface that provides the predicted RLEM hatch date for a user-defined location.
- Historical data on RLEM life history, diapause, and pesticide response was compiled to investigate the influence of climate change on the effectiveness of the TIMERITE® pest management strategy.
- Six novel modes of action (MoA) and two biological products were tested in a series of microcosm trials on pasture.
- Two candidate chemicals that showed high levels of efficacy against RLEMs in these microcosm trials were progressed to being tested under field trials in 2023.
- A social benchmarking project investigating the knowledge, practices and attitudes of growers and advisors relating to RLEM insecticide resistance management was developed to understand how

chemical-based management of RLEM is influenced by variables such as risk attitude, risk perception and knowledge.

- A wide range of extension activities were planned to support graziers and advisors in adopting and testing the tools, findings, and recommendations derived from the project.

Results/key findings

- There was a significant increase in detections of RLEM insecticide resistance in eastern Australia, particularly within SA. Of the 49 populations screened as part of this project, five populations were found to possess OP resistance, two with SP resistance, and four with dual resistance to both OPs and SPs.
- The testing of novel MoA and biological products under microcosm and bioassay trials ruled out many products as having potential for RLEM control, identifying two candidate chemicals that indicted high efficacy. Field testing of these two products did not show the same level of efficacy.
- Climatic variables enhance diapause prediction and significantly improved the accuracy of predicting diapause onset in RLEM, compared to using only daylength and growing season length as in the original TIMERITE® model. Climate change impacts TIMERITE® efficacy with changing temperature and rainfall patterns over the past three decades reducing the effectiveness of the original TIMERITE® model, leading to lower control efficacy. The hatch timing tool successfully predicted the hatch timing of RLEM, enhancing early season monitoring under variable climates.
- The benchmarking study provided insights into the spray frequency of different chemical groups used by producers and recommended by advisors, with producers and advisors exhibiting distinct risk attitudes, with economic impacts a primary concern for producers and advisors, emphasising the importance of trialling new practices.
- Cesar Australia and MLA have been working closely together to successfully produce extension and communication outputs for the project, including the development of online training modules and articles. The PDS project has been an opportunity to showcase and promote key outputs.

Benefits to industry

- New knowledge gained through the project will be fed into the new version of the RLEM Resistance Management Strategy (RMS), ensuring it provides the best practice recommendations for RLEM control.
- The hatch timing tool will increase the monitoring precision of RLEM and thus minimise pest risk.
- The updated TIMERITE® offers significant benefits to the red meat industry by minimising RLEM impacts, improving pasture productivity and quality, reducing pesticide use and input costs, and enabling adaptation to climate change.
- The gained insights from the social benchmarking study will play an important role in enhancing communication and extension outputs.
- The PDS project ‘Less Mites, More Feed’ is being conducted in collaboration with 15 core producers (representing 28,000 ha of managed land, 86,000 sheep, and 3,000 cattle) and 93 observer producers (representing over 150,150 ha of managed land, over 505,000 sheep, and 15,000 cattle).
- Forthcoming extension outputs will benefit the industry by increasing awareness about the identification and biology of different pest mites and highlighting the longer-term implications of resistance.

Future research and recommendations

- Future management of RLEM should aim to reduce the use of chemicals to limit selection pressures and decrease the risk of further local resistance evolution.
- Ongoing resistance surveillance to monitor the distribution and levels of field resistance is crucial to identify emerging resistance issues. Understanding the incidence, patterns of spread, and current distribution and nature of resistance is also important for the RMS. In addition to OPs and SPs, it is important to explore any arising potential resistance to neonicotinoids in RLEM. Providing growers and advisors a resistance testing service allows them to implement effective resistant management strageties and improve management outcome to ensure effective pest control in the future.
- It is important to continue to explore and support any novel MoA and biological products being considered for RLEM control and registration.
- It will be critical to ensure that the RLEM RMS is continually updated with the latest research and best management practice recommendations. It is recommended that the RLEM RMS is extensively promoted to increase awareness and adoption of its recommendations by meat and livestock growers and advisors.
- Facilitating the extension of research findings holds a crucial role in advancing industry knowledge and fostering adoption in future initiatives addressing RLEM resistance and control. Education is a key component, empowering growers and advisers to confidently adopt new resistant management strategies and decisively move away from control strategies that increase the risk of resistance evolving in RLEM and other pests.
- It is recommended that MLA continue to work in collaboration with other industries impacted by RLEM to improve the management of RLEM and reduce its significant current economic impact.

Table of contents

Abstract 2
Executive summary 3
1. Background 8
2. Project objectives 8
2.1 Resistance monitoring 8
2.2 Targeted monitoring and control 8
2.3 Testing novel modes of action against RLEM 8
2.4 Social benchmarking and extension 8
3. Methodology 9
3.1 Resistance monitoring 9
3.2 Targeted monitoring and control 10
3.2.1 Hatch timing tool 10
3.2.2 Spray timing tool 13
3.3 Testing novel modes of action against RLEM 13
3.3.1 Microcosm trials 13
3.3.2 Field trials 14
3.4 Social benchmarking and extension 15
3.4.1 Social benchmarking 15
3.4.2 Extension Plan 16
4. Results 16
4.1 Resistance monitoring 16
4.2 Targeted monitoring and control 17
4.2.1 Hatch timing tool 17
4.2.2 Spray timing tool 19
4.3 Testing novel modes of action against RLEM 20
4.3.1 Microcosm trials 20
4.3.2 Field trials 27
4.4 Social benchmarking and extension 27
4.4.1 Social benchmarking 27
4.4.2 Extension Plan 34
5. Conclusion 40

5.1 Key findings 40
5.2 Benefits to industry 42
6. Future research and recommendations 43
7. References 45

1. Background

The redlegged earth mite (RLEM) is consistently ranked as one of the most important pests of pastures, affecting the production and profitability of red meat producers in southern Australia. Estimated losses of seed production of as much as 50% in annual pasture legumes and annual pasture production are valued at $281-462 M. This project has been exploring new understanding of the vulnerabilities in the RLEM lifecycle at diapause and hatching to improve and develop pest forecasting tools for livestock producers. The tools will allow producers to respond to increasingly variable climatic conditions through well-timed control strategies that maximise their impact. Importantly, this investment was leveraged against existing multi-year GRDC ($2.6M over 5 years) and AgriFutures ($88.9K over 3 years) investments, delivering a high return for red meat producers.

Insecticides are currently the most effective and widely used control method against RLEM but increasing insecticide resistance to synthetic pyrethroids (SPs) and organophosphates (OPs) requires new management options. The project has been building on the ongoing GRDC investment to validate the forecasting models for predicting diapause (spray timing tool) and hatching (hatch timing tool) for the optimum control of spring populations in pasture systems. Overarching project outcomes include enhanced farm profitability through improved control strategies for RLEM, increased producer confidence in RLEM seasonal risk, impact potential, and appropriate control options that will maintain the long-term effectiveness of current chemical control options through resistance management strategies.

2. Project objectives

2.1 Resistance monitoring

Between 2021-2023, conduct targeted field collections of 15 RLEM populations across south Australian red meat production regions to understand the current extent of resistance issues and control failures. This will support the prioritisation of future research needs, development of resistance management strategies, and availability of effective chemical controls.

2.2 Targeted monitoring and control

Between 2021-2022, deliver decision support tools through validating a new GRDC web tool predicting RLEM egg hatch and updating AWI's TIMERITE® diapause tool based on current regional environmental conditions in red meat production systems. Predictions will be validated through field collections that quantify the timing of RLEM diapause onset. Improved pest forecasting tools will allow red meat producers to respond to increasingly variable climatic conditions through well-timed monitoring and control strategies that target pest life-cycle vulnerabilities and early-season risk more accurately.

2.3 Testing novel modes of action against RLEM

Working with agro-chemical and biotechnology companies, identify new synthetic insecticide options against RLEM and explore potential of biological molecules through lab trials and pasture trials. This will ensure any actives identified through this project are thoroughly tested in pasture environments, which is an essential requirement for new insecticide options to become available for producers to effectively manage resistant RLEM.

2.4 Social benchmarking and extension

In year 1 expand grains industry focused social research on current knowledge, attitudes and practices into pasture -based industries, reporting on the findings of this research to MLA and what it indicates in terms of

knowledge gaps, and how outreach and education activities should be framed and directed. In year 1 and 2 work with producer groups and the Producer Demonstration Site (PDS) team at MLA to explore and design a PDS that will support producers in testing research-led management advice and sharing findings within and outside of the group. This PDS project has now commenced across four demo sites in two regions in Victoria. The project has 15 core producers (representing 28,000 ha of managed land, 86,000 sheep, and 3,000 cattle) and 93 observer producers (representing over 150,150 ha of managed land, over 505,000 sheep, and 15,000 cattle).

3. Methodology

3.1 Resistance monitoring

Through the wider GRDC investment, RLEM resistance screening was undertaken across southern Australia (NSW, SA, Vic and WA) in the winter growing seasons between 2021 and 2023. As part of this screening, approximately 485 RLEM populations were collected from the field and screened for resistance through phenotypic discriminating bioassays and/or genetic markers (*kdr* genotyping) targeting the known resistance mechanism for SPs. The phenotypic bioassay used discriminating concentrations of bifenthrin, omethoate, chlorpyrifos and malathion, which are known to separate resistant from non-resistant mites based on past studies. The *kdr* genotyping detects population resistance allele frequencies for SPs. Of all the populations screened, 49 populations were screened as part of the MLA co-investment, which supported the targeted screening of pasture sites from red meat production regions (Fig. 1). Populations were mostly collected from a mixture of reported control failures and paddocks with high pesticide and cropping usage. The research investment was promoted extensively throughout the season (through grower group newsletter articles, PestFacts, press releases and presentations) to ensure that growers and advisors were aware and able to utilise the RLEM resistance screening service.

A standardised sampling method was undertaken at each collection site which helped address other project objectives. Paddock information such as location, grower details, vegetation cover, crop details and presence of native vegetation refuges was recorded. We also collected detailed information on the cropping and pesticide history from the previous five years. At each site, mites were collected via suction using a Stihl SH55 blower vacuum with a fine gauze mesh placed over the end of the vacuum tube. Mites were placed into a plastic container with paper toweling and vegetation, and then transported back to the laboratory. Containers were stored in a fridge at 4°C until mites were required for testing.

Mite populations were screened for SP and OP resistance via laboratory bioassays, following the methodology described in Arthur and colleagues (2021). For all bioassays undertaken, a known insecticide susceptible RLEM population was included as a control and tested alongside the mite populations being screened for resistance. To screen for the presence of SP resistance, a discriminating dose of bifenthrin was tested (100 mg a.i./L), along with a water control. Populations were classed as resistant if there were survivors at this dose and no survivors in the susceptible population. To screen for the presence of OP resistance, discriminating doses of omethoate (5.8 mg a.i./L), chlorpyrifos (21 mg a.i./L) and malathion (500 mg a.i./L) were tested, along with a water control. Populations were classed as resistant if mortality was < 90% for any of the OP chemicals tested or if multiple chemicals had survivors and there were no survivors in the susceptible population.

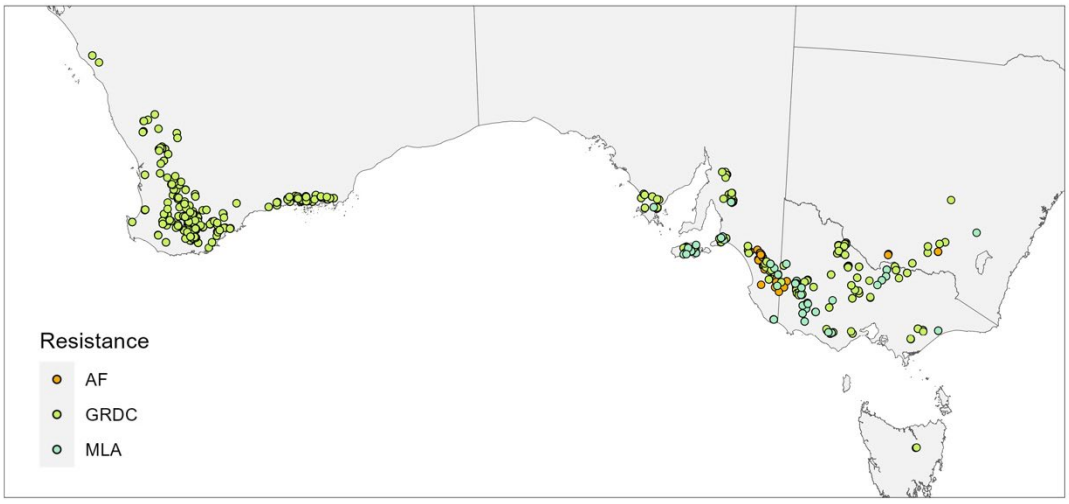
For each chemical and dose tested, the insecticide solution (with the addition of a non-ionic surfactant [Tween 20] at 0.01% to aid the spread of the insecticide and ensure even coating) was poured into a plastic vial (15 mL) and swirled to ensure complete coating, with excess liquid discarded. Six vials were coated per concentration and were left to dry overnight. Control vials were treated in the same way, except water (with the addition of 0.01% Tween) was used. Approximately eight RLEM adults were placed into each vial, along with 2-3 leaves of common vetch, which provided food and humidity. Vials were then sealed with a screw lid and placed in a controlled temperature cabinet at 18°C, with a L16:D8 photoperiod. After 24 hours exposure, mites were scored as alive (moving freely), incapacitated (inhibited movement), or dead (no movement over a

5 s period). Incapacitated individuals were pooled with dead individuals for analysis, as they invariably die and therefore do not contribute to the next generation.

Molecular screening for SP resistance was undertaken on populations where numbers were insufficient to undertake phenotypic laboratory bioassays, as well as on a subset of populations where phenotypic bioassays indicated resistance. This was done by testing mites for *kdr* mutations known to confer SP resistance. Mite populations that exhibited a *kdr* mutation frequency of more than 2% were classified as resistant. To undertake this testing DNA was extracted from pooled mite samples (10–50 mites) from the population using a Qiagen DNeasy Blood & Tissue Kit. Samples were quantified using a Qubit and normalised to 1 ng µL. TaqMAN SNP genotyping assays were designed to detect two single nucleotide polymorphism resistance mutations in the RLEM parasodium channel gene (TTG → TTT) and (TTG →TTC), which both produce a leucine (L) to phenylalanine (F) amino acid substitution (L1024F) as described in Edwards and colleagues (2018).

Following screening, growers and/or advisors were provided with a full report outlining whether resistance was detected in mites collected in their paddock and, if present, the type of resistance found. The report was accompanied with management recommendations specifically tailored to the type of resistance present. This information can assist growers and advisors to implement effective resistant management strageties and improve management outcome to ensure effective pest control of RLEM in the future.

Figure 1. Location of all sampling sites collected throughout 2021-2023 for GRDC (green), MLA (blue) and AgriFutures (orange).



3.2 Targeted monitoring and control

3.2.1 Hatch timing tool

We extended a previous study on predicting hatch dates from regional temperature and rainfall conditions (McDonald et al. 2015) to an easy-to-use web interface that provides the predicted hatch date for a user-defined location. This includes an option for real-time weather data for the current growing season, or long-term average conditions.

End user feedback

After completion of a draft interface, feedback from end-users was sought through a webinar promoted by SARDI PestFacts and PestFacts southeastern, a focus group at a GRDC grower network meeting, and

producers via a parallel PDS program. For the focus group – facilitated by Belinda Cay, using the Group Map elicitation software – several questions were posed to the group to provide direction for future development of the tools to best meet the needs of growers:

Would an accurate forecast of hatch date help your monitoring and management activities?

Under what circumstances would you use such a tool?

Would you prefer such tools to be integrated with other digital ag services (e.g. AgWorld, Back Paddock, Planfarm) or with grains management resources (e.g. GRDC website and/or Cesar Australia PestNotes?)

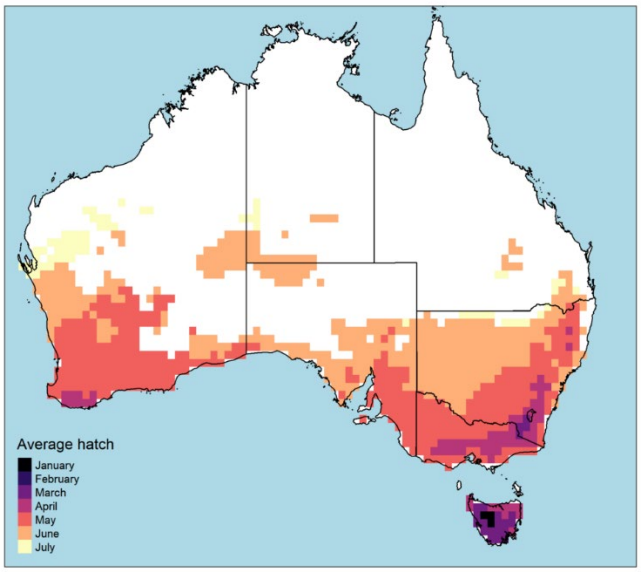
What other improvements or considerations can you suggest to improve usefulness to growers?

Some users thought the tools would help target monitoring, particularly in high-risk situations, but there was a large appreciation of the role of prophylactic treatments (seed treatments, bare earth sprays, and tank mixes), which were seen as a barrier to a monitoring-based management approach.

Other users called for more information on mite abundance at hatching. In terms of interfaces, some users thought it might be more convenient to integrate with other digital agriculture platforms (e.g. AgWorld), while other, particularly independent advisers, thought a standalone tool would be preferable. In any case, seasonal reminders of the availability of such tools were seen to be useful (e.g. through industry updates). Integration of additional pests and linking to other resources and tools was suggested.

For the PDS, an additional irrigation option was added to the web tool, following feedback from the Kyabram Producer Group facilitated by Matt Mahoney from Agridome, which asked for the possibility of incorporating the effects of irrigated paddocks on hatch time.

Figure 2. The mean predicted hatch month for different climatic regions in Australia using gridded climatic data spanning the 20 years from 1996 to 2015.



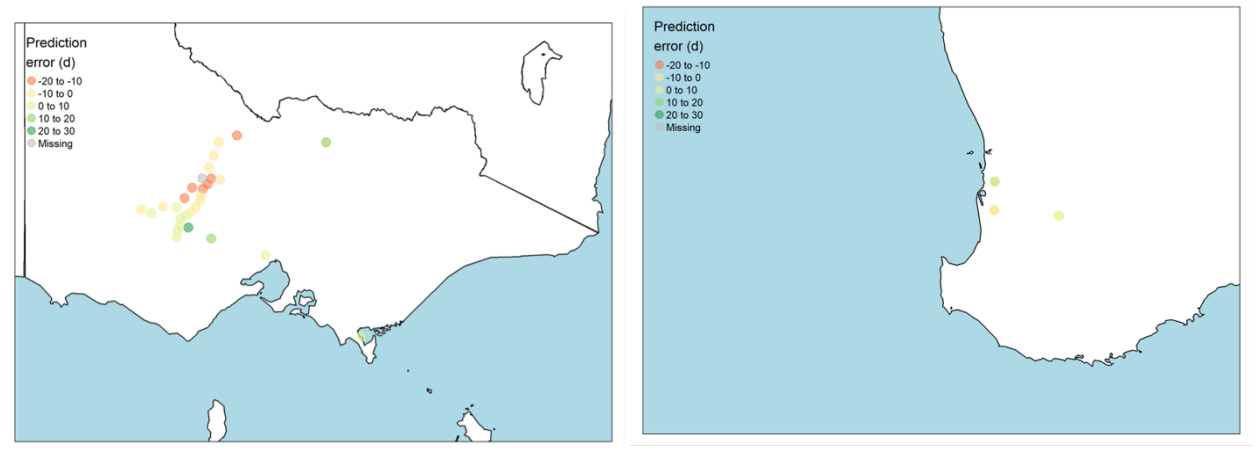
Model validation

To validate the predictions, on 17 June 2022, during the period of predicted mite hatching, we compared predicted hatch times with observed hatch times across different climatic zones (Fig. 2).

We sampled along two roadside transects running from north to south into higher rainfall zones in Victorian grain growing regions. The first transect spanned Stoneleigh to Bendigo, with randomly selected locations separated by approximately 10 km. The second transect spanned Lockington to Ararat, with samples separated by approximately 20 km.

Mites at each sample point were collected from suitable vegetation along roadsides within 20 m from the car adjacent to grain crops and pastures using vacuum sampling. Mites were sampled until at least 50 mites had been accumulated, which was usually achieved with one sample (approximately 20 seconds of vacuuming). If no mites were found, mites were marked as absent, which only occurred in one sample.

Figure 3. A total of 40 samples (with one site with no mites found) were included as part of the RLEM hatch model validation. The circles indicate sample points collected from the literature review and field transects for Victoria (left) and WA (right). The colour of the circle indicates the prediction error when compared with the model.



The collected mites were funneled into eppendorf tubes filled with 70% ethanol. The following day, 50 randomly selected mites were spread onto a white dish and categorised into their life-stage with a dissecting microscope using the morphological description provided by Baker (1995).

Following McDonald and colleagues (2015), the hatch date was estimated by subtracting the estimated duration from hatching until the observed life stage at collection; that is, development times for larva, protonymph, deutonymph, tritonymph, and adult, were taken at 2, 6, 11, 16, and 21 days, respectively.

Additional hatch dates found from a literature search conducted by McDonald and colleagues (2015) were also included in the analysis, resulting in 25 samples from the present study and 15 samples from the literature review.

Comparison of the observed hatch dates with predicted hatch dates revealed that the model error was no more than 15 days across all samples, with a mean error (and standard error) of -4.68 (4.03) days. The negative bias suggests that the model tended to overpredict the hatch dates. This bias may be useful, as mites would be difficult to observe within the first few days of hatching due to their small size. Even in the case of the largest error of 15 days, mites are unlikely to have reached their most economically injurious life stage (i.e. the adult phase), which should allow sufficient time for intervention where necessary. The sample locations and prediction errors for each site are shown in Figure 3.

3.2.2 Spray timing tool

To investigate the influence of climate change on the effectiveness of the TIMERITE® pest management strategy for RLEM, we compiled historical data on their life history, diapause, and pesticide response. These data have been digitised and made publicly available (https://data.csiro.au/collection/csiro:58719).

We developed a series of logistic regression models to predict the onset of diapause in RLEM, incorporating historical field data on diapause status and climatic variables such as daylength, growing season, temperature, and rainfall. We then created a simulation model to estimate the efficacy of pesticide applications at different timings, integrating sub-models for RLEM population dynamics, pesticide-induced mortality, and diapause status. The simulation model was validated against field data on RLEM abundance following pesticide applications at different times relative to the TIMERITE® date. Finally, we compared the efficacy of the original TIMERITE® model against two modified versions that incorporated dynamic climate data and a dynamic diapause offset, using annual climatic conditions from 1990 to 2020 across the Australian range of RLEM.

The detailed methods, results, and research outcomes of this work are available here: https://www.researchsquare.com/article/rs-3680620/v1.

3.3 Testing novel modes of action against RLEM

3.3.1 Microcosm trials

As part of our collaborative research with agro-chemical companies and supported through the RLEM investments (GRDC, MLA, and AgriFutures), we undertook a series of microcosm trials on pasture. We tested nine treatments, which included six novel modes of action (MoA) and two biological products (Table 1). These treatments were tested against RLEM using a microcosm approach under semi-field conditions on a pasture mix consisting of ryegrass, subterranean clover, phalaris, plantain, cocksfoot, white clover and common vetch. This methodology has been used previously to determine numerous aspects of pest biology, including responses to insecticides (Kirkland et al. 2018, 2023). Between one to three rates of each product were tested and compared against the commercial standard Le-Mat (omethoate) and an untreated control. A total of 25 treatment combinations were tested across the trials.

Seeds were sown into clear plastic containers (35 x 24 x 26 cm) using a sandy loam soil mix. Four replicate tubs were assigned for each treatment. Once plants had reached an appropriate stage, RLEM were collected from a known insecticide-susceptible population. Mites were collected via suction using a Stihl SH55 blower vacuum with a fine gauze mesh placed over the end of the vacuum tube. Mites were placed into plastic containers with paper toweling and vegetation, and then transported back to the laboratory. Containers were stored in a fridge at 4°C until mites were introduced into the tubs. The day before spraying treatments, approximately 800 mites were added into each tub in Trials 1, 2 and 3 and 500 mites were added into each tub in Trial 4.

Treatments were applied using an Inter 16 L knapsack with hand-held lance and TeeJet Turbo TwinJet Twin Flat Spray nozzle (TTJ60-11002). Plants were sprayed at a height of 50 cm and pressure was maintained at 300 kPa. A total volume of 1 mL was applied per tub, replicating a water rate of approximately 100 L/ha. The number of RLEM within each tub was directly counted at 3, 7, 10 (Trials 1, 2 & 3)/ 11 (Trial 4) and 14 days after treatments (DAT). Plant feeding damage was assessed visually in all tubs at the same interval using a 0-10 scale, where 0 represents no visible feeding damage, 5 equals 50% damage and 10 represents all plants damaged/dying. Phytotoxicity was assessed on a scale of 0-10, where 0 represents no phytotoxicity and 10 represents all leaves affected.

3.3.2 Field trials

Discussions were undertaken in early 2023 with all the relevant chemical companies regarding the results of the MoA/biological trial work undertaken in 2021 and 2022 as part of the collaborative RLEM research investments, which extended beyond the pasture trials reported here. From these discussions we identified two candidate chemicals (Product A and Product B) that showed high levels of efficacy against RLEMs in these microcosm trials from two different chemical companies. These two chemicals were progressed to being tested under field trials in 2023.

Table 1. Chemical treatments and rates tested under microcosm trials on pasture. The product tested and the results are to remain confidential and should not be communicated or shared outside of MLA.

Trial no.	Treatments	Field rates tested	Product
1	Product 1	1.00% 0.50% 0.25%	Biological
	Product 2	400 mL/ha 600 mL/ha 800 mL/ha	Novel MoA
2	Product 3	2500 mL/ha 3000 mL/ha 3500 mL/ha	Novel MoA
	Product 4	500 mL/ha 750 mL/ha 1000 mL/ha	Novel MoA
	Product 5	500 mL/ha 750 mL/ha 1000 mL/ha	Novel MoA
3	Product 6	100 + 300 mL/ha 133 + 400 mL/ha 200 + 600 mL/ha	Novel MoA
4	Product 7	463 mL/ha 695 mL/ha 926 mL/ha	Biological
	Product 7 + Product 8	463 + 37.50 mL/ha 695 + 37.50 mL/ha 926 + 37.50 mL/ha	Biological + Novel MoA
	Product 8	37.50 mL/ha	Novel MoA
1, 2, 3 & 4	Le-Mat (omethoate)	100 mL/ha	Registered product

The field trials were undertaken by DPIRD in WA. One trial was undertaken in Manjimup on canola; the other in Boyup Brook on an established long term pasture paddock (clover and grasses). At each trial, seven treatments were tested: Product A (3 rates), Product B (2 rates), untreated control, and a conventional standard (Le Mat).

Both trials were established in July 2023. In each, 28 plots, measuring 12 x 12 m, were pegged out and randomly allocated one of seven treatments. Four replicate plots were allocated for each treatment. For each trial, either the day the chemical treatments were applied or the day before, plots were sampled for mites via suction using a Stihl SH55 blower vacuum. Four samples were randomly taken within a 30 x 30 cm (pasture trial) and 60 x 30 cm (canola trial) frame in the central 10 x 10 m area of each plot, and then transferred to vials filled with 70% ethanol and brought back to the laboratory, where RLEM numbers were counted using a stereomicroscope. In the pasture trial, blue oat mites were also present and counted separately. Plant feeding damage, plant density (in the canola trial), and phytotoxicity assessments were also undertaken (four times in each plot). Plant damage score was an estimate of overall damage caused by mites. This was based on a 0-10 scale, where 0 is no visible damage, 5 is 50% damage, and 10 all plants are dead/dying. The phytotoxicity score followed the same scale, but was based on symptoms, including leaf speckling, necrosis, and yellow or brown blotches. Phytotoxic effects were not seen in either trial on any sampling day. Plots at both sites were then sprayed with the assigned treatments using a Silvan TPL boomsprayer, with DG11002VP nozzles, at two bar spray pressure. All treatments were applied at 156 L/ha in dry conditions when average wind speeds were 3 km/h. Treatments were applied on the canola trial when plants were between the 1st and 2nd leaf stage. Following spraying, mite and plant assessments were undertaken in each plot at 3-, 7- and 14-DAT, with a 28-DAT score also undertaken in the pasture trial.

3.4 Social benchmarking and extension

3.4.1 Social benchmarking

As part of the wider GRDC investment, we developed a social benchmarking project investigating the knowledge, practices and attitudes of growers and advisors relating to RLEM insecticide resistance management. This social science research was developed to help understand how chemical-based management of RLEM is influenced by variables such as risk attitude, risk perception and knowledge.

The online survey was developed in collaboration with the University of Melbourne and was designed for grower or advisors in Australia who had previous experience in managing or advising management of RLEM. The questions were divided into the following categories: (1) demographics; (2) insecticide use patterns; (3) attitude towards risk in their management practice/advice; (4) knowledge of RLEM and insecticide resistance; and (5) connectivity in their community. Participants were asked about their occupation and given the choice of *grower*, *industry advisor* or *neither*. Both *grower* or *industry advisor* responses branched the survey into a slightly different set of questions, while the *neither* answer ended the survey. We note that, unfortunately, we might have missed livestock producers that may have identified as neither growers nor advisors. Both growers and advisors were asked a range of questions to test their knowledge of RLEM resistance, mite species identification, RLEM lifecycle, and non-chemical management options.

The survey comprised 24 questions and took around 10 mins to complete and was delivered via Qualtrix. It was distributed through the newsletters and social media of the project partners and advertised through conversations with the patterns' network of growers and advisors. A media release was also distributed via the GRDC and MLA. We made additional efforts to distribute the survey in WA, as this is where insecticide resistance issues for RLEM were first detected. The survey was open from October 2021 to February 2022. Participants who completed the survey were rewarded with early access to online training materials.

3.4.2 Extension Plan

We planned a wide range of extension activities to ensure that levy payers were aware of project progress and achievements, and, importantly, to support graziers and advisors in adopting and testing the tools, findings, and recommendations derived from the project. The extension activities fall into the following categories:

- Social research/knowledge benchmarking
- In-field extension (PDS)
- RLEM online training modules
- Project extension and communication

These are discussed in full detail in the project's Extension Plan, which has been already submitted to MLA.

4. Results

4.1 Resistance monitoring

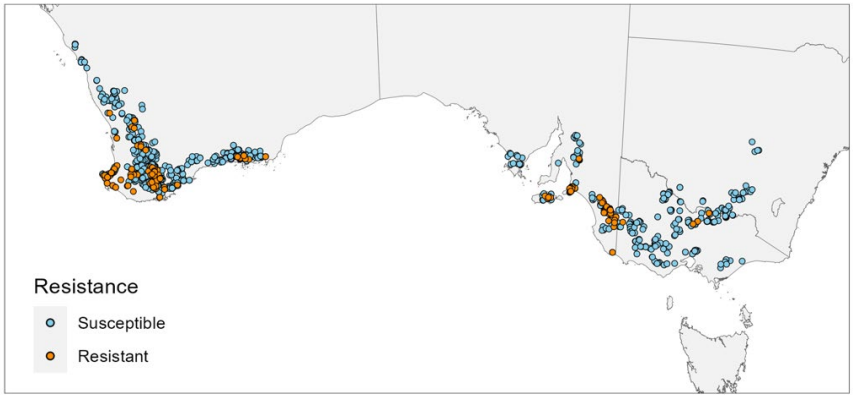
Of the 485 RLEM populations screened between 2021 and 2023, close to 200 have shown to be resistant. In WA, 75 were found to possess resistance to SPs, 9 to OPs, and 43 with dual resistance to both SPs and OPs. In eastern Australia, 11 were found to possess resistance to SPs, 37 to OPs, and 24 with dual resistance to both SPs and OPs. Organophosphate resistance appears to be more common in eastern Australia than SP resistance, whereas SP resistance is more common in WA.

Of the 49 RLEM populations specifically screened as part of this project, 11 were found to possess resistance. These were found within South Australia (Kangaroo Island, north of Adelaide, Fleurier Peninsula and the south-east coast) and the north central region of Victoria. Through this current screening, resistance has been detected in several new regions within eastern Australia.

Within WA, the current distribution of SP and OP resistance in RLEM is widespread, covering the southwest, great southern, south coastal, and wheatbelt regions (Fig. 4). RLEM resistance appears to be increasing in WA, with new resistant populations being detected each year. In 2022, RLEM resistance to OPs was detected for the first time in the southern coastal regions of WA. Many populations that were found to be resistant in WA were also collected from pasture paddocks used for livestock.

The current resistance status of RLEM to OPs and SPs in Australia is shown in Figure 4.

Figure 4. Current resistance status of RLEM as of 2023 to OPs (top) and SPs (bottom).



4.2 Targeted monitoring and control

4.2.1 Hatch timing tool

Web application and user-interface

The final version of the hatch tool is available here: https://cesaraustralia.shinyapps.io/RLEM-hatch/. Following feedback from end-users the app has been optimised for a variety of smartphone, tablet and laptop screen sizes and can be embedded as an interactive panel in online digital communications (e.g. PestFacts articles) around the time of monitoring and relevant management decisions.

The app has two tabs, *Estimate* and *About*. The *Estimate* tab (Fig. 5, left) shows a simple output of the hatch estimate, while the *About* tab (Fig. 5, right) shows additional information, including current climatic data for the season up to the present date. Once temperature and rainfall conditions for the current season have been met, the hatch date will be indicated on the graph that shows local rainfall and temperature conditions according to the SILO climatic database (Fig. 6).

Figure 5. User interface for the hatch prediction app, showing the *Estimate* (left) and *About* (right) tabs. The location selector in the *Estimate* tab allows users to easily select their location of interest. Irrigation options allow the user to specify any irrigation applied to the paddock, which may accelerate hatch date.

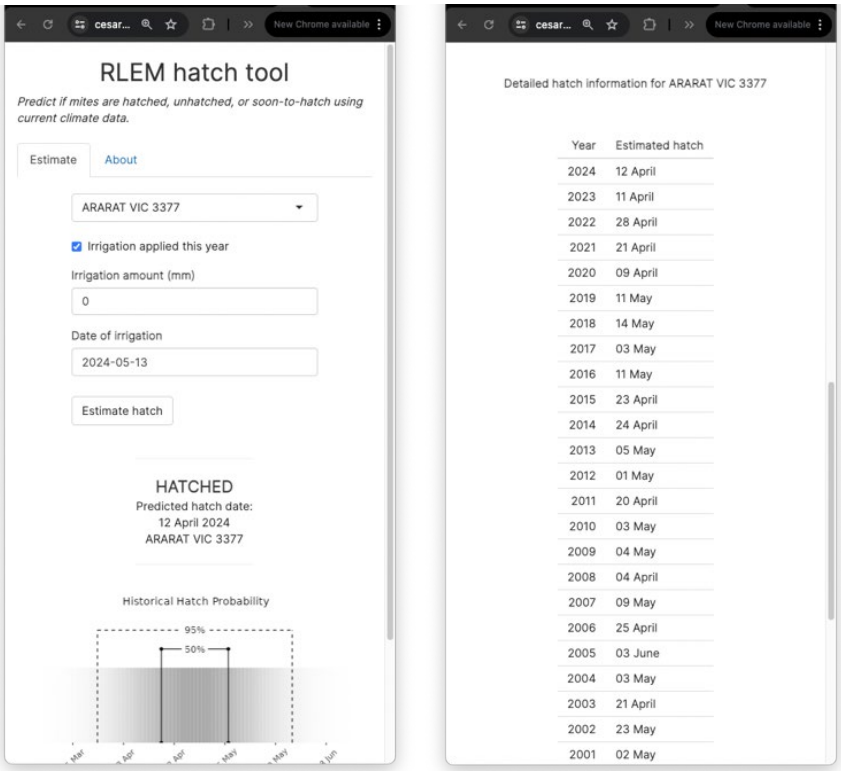
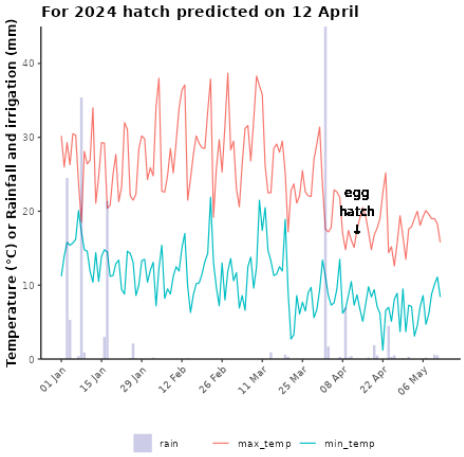


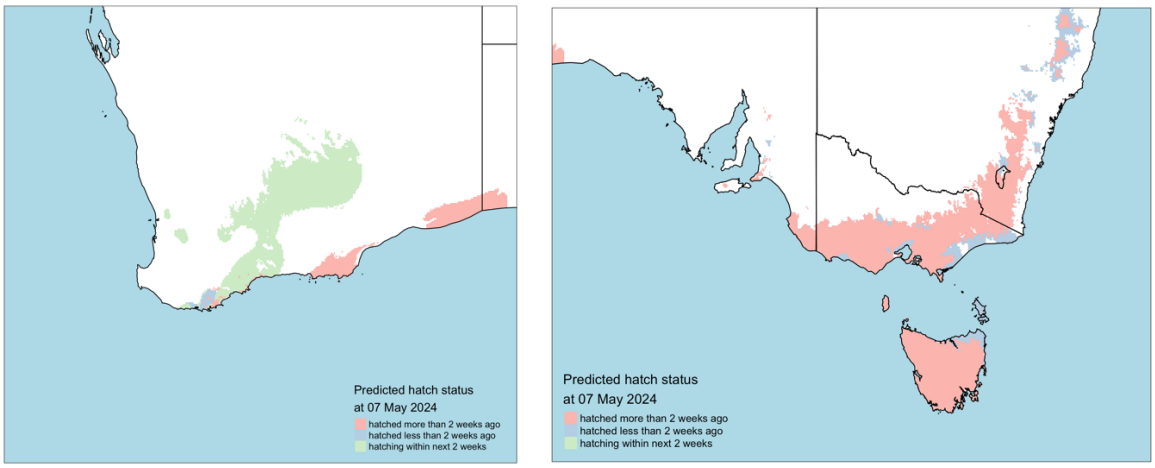
Figure 6. Temperature and rainfall for the 2024 season in west Victoria are used to predict the hatch date for RLEM.



Hatch prediction map

To help facilitate quick visualisation of regional RLEM hatch status, we also developed the option to generate hatch prediction maps (Fig. 7). Due to the computational processing required for gridded estimates across the continent, the program is housed on Amazon Web Services and is not intended to be made widely available to the public. Rather, extension scientists will be given access, who can then easily share the maps through their networks, including PestFacts and other industry extension outlets.

Figure 7. Regional predictions of hatch likelihood based on the season's climatic conditions on 7 May 2024.



4.2.2 Spray timing tool

A major finding is that optimal spray dates are expected to have shifted by a mean of 27 days earlier in the season across the locations as shown in Figure 8. Spraying according to these new dates could increase efficacy of control by nearly 30% on average compared to the original TIMERITE® model.

Update to TIMERITE® *web interface*

Several meetings have been convened with representatives from GRDC, MLA, AWI, CSIRO, and Cesar Australia to discuss the roll out of the research findings to growers and producers via an update to the existing TIMERITE® interface.

A draft user interface (Fig. 9) is available here: https://cesaraustralia.shinyapps.io/timerite.

An API for the updated TIMERITE® model (for incorporation into other interfaces) is available here: https://rlem-diapause-cdsy77yrna-uc.a.run.app/__docs__/.

Ultimately, AWI will update the TIMERITE® interface using this API. A multiparty agreement between RDCs will ensure the longevity of the service, any maintenance requirements are met, and acknowledgement of co-funding. Once finalised, the involved RDCs will coordinate industry communications regarding the TIMERITE® update.

Figure 8. Projected shifts in the optimal timing of control as forecasted by the updated TIMERITE® model, juxtaposed with the predictions from the original model for selected locations spanning the range of RLEM. In the visualisation, green dots indicate a positive delay, signifying that optimal control is anticipated to occur later in the year compared to the TIMERITE® model predictions. Conversely, red dots indicate a negative delay, indicating that optimal control is expected to happen earlier in the year. The colours also correspond to the delay values depicted in the accompanying frequency histogram.

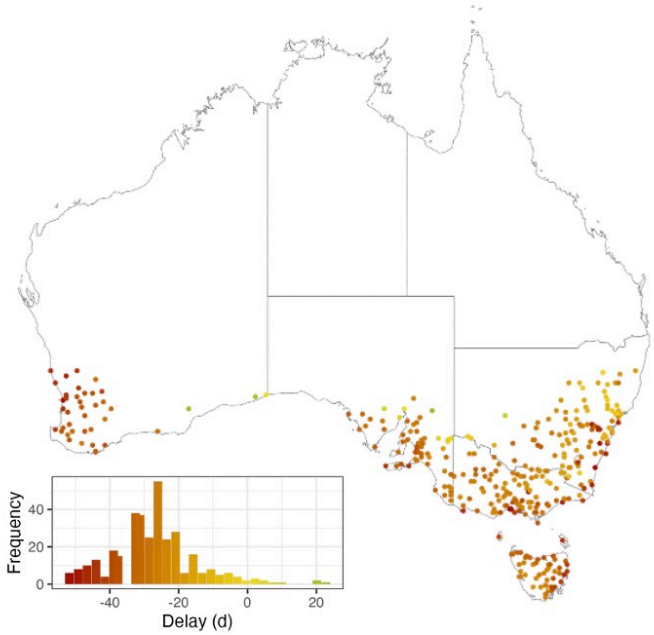
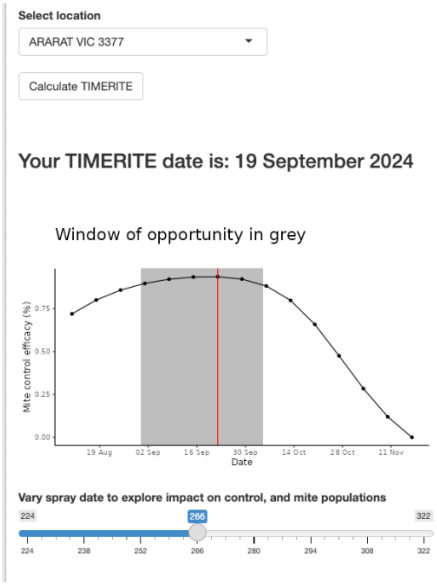


Figure 9. Draft user interface for updated TIMERITE® model where users can easily select their location and see how RLEM control efficacy is expected to vary with alternative spray dates.



4.3 Testing novel modes of action against RLEM

4.3.1 Microcosm trials

Products 1, 2, 3 and 4 did not confer efficacy against RLEM or offer protection from mite feeding when applied as foliar treatments on pasture (Tables 2 & 3; Figs. 10 & 11). On the contrary, Products 5, 6, 7 and 8 provided some level of efficacy against RLEM, as well as protection from mite feeding (Table 2 & 3; Fig. 10 & 11). However, there were differences in the level of protection provided by the different products and in most cases the level of control offered by these products was not as high as that provided by the commercial product Le-Mat (omethoate).

Of the products tested, Product 6 and the two higher rates of Product 5 (750 and 1000 mL/ha) provided the highest level of efficacy against RLEM, with significant reductions in mite numbers at a level similar to the commercial product Le-Mat. Similarly, these products also offered a high level of protection from mite feeding damage, at a level similar to the commercial product Le-Mat.

Additional microcosm trials and bioassays on other plant hosts and chemicals were undertaken as part of the boarder collaborative RLEM research investments. In total, 21 chemical treatments, including 16 different chemicals, which included both novel MoA and biological products were identified and tested during this period. Results from all the trials undertaken in 2021 and 2022 were analysed closely and discussions were undertaken with the relevant agro-chemical companies to discuss next steps and identify any potential chemicals that had shown efficacy in these trials that were worth pursuing to field trials. Additionally, there had to be a genuine interest from the agro-chemical companies to register the product against RLEM, if promise was shown in the field trials.

Table 2. Average number of RLEM at each sampling date and results from one-way ANOVAs comparing treatments for the four trials. Different letters indicate significantly different means at each sampling date (at the *P* < 0.05, Tukey's-*b* post hoc test).

Trial	Treatments	3-DAT		7-DAT		10/11-DAT		14-DAT	
1	Untreated control	793	a	738	a	222	a	87	a
	Product 1 @ 0.25	778	a	630	a	120	a	25	a
	Product 1 @ 0.5	762	a	466	a	101	a	24	a
	Product 1 @ 1	808	a	642	a	187	a	66	a
	Product 2 @ 400	708	a	486	a	167	a	60	a
	Product 2 @ 600	706	a	431	a	136	a	69	a
	Product 2 @ 800	696	a	547	a	131	a	54	a
	Le-Mat	0	b	0	b	0	b	0	b
	P value	<0.0001		<0.0001		<0.0001		<0.0001	
	F-statistic	1446.35		85.91		21.65		17.80	
	df	7, 25		7, 25		7, 25		7, 25	
2	Untreated control	793	a	738	a	222	a	87	ab
	Product 3 @ 2.5	786	a	616	ab	168	ab	43	ab
	Product 3 @ 3	759	a	587	ab	155	ab	83	ab
	Product 3 @ 3.5	755	a	591	ab	74	ab	41	ab
	Product 4 @ 500	809	a	640	ab	191	ab	86	ab
	Product 4 @ 750	800	a	678	ab	273	a	127	a
	Product 4 @ 1000	791	a	706	ab	182	ab	69	ab
	Product 5 @ 500	738	a	404	b	109	ab	48	ab
	Product 5 @ 750	250	b	58	c	32	b	20	b
	Product 5 @ 1000	214	b	38	c	22	b	18	b
	Le-Mat	0	c	0	c	0	b	0	b
	P value	<0.0001		<0.0001		<0.0001		0.001	
	F-statistic	78.24		19.58		4.89		3.92	

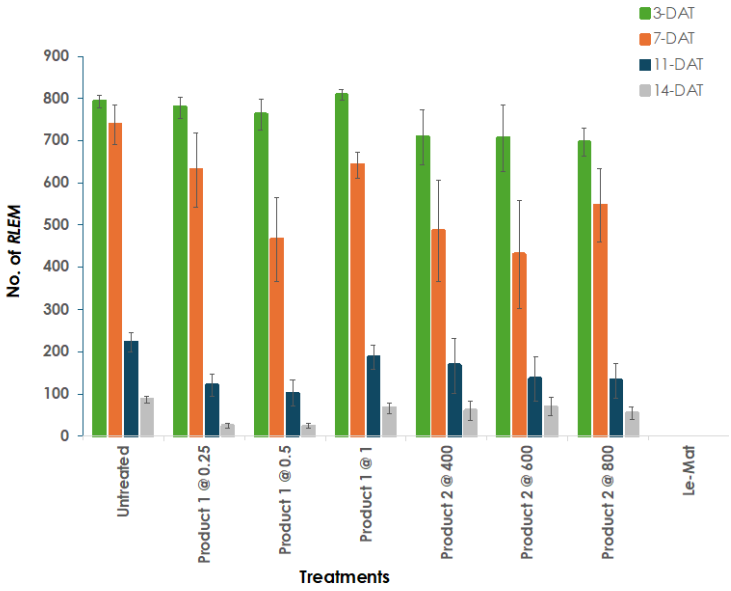
	df	10, 34		10, 34		10, 34		10, 34	
3	Untreated control	792	a	738	a	222	a	87	a
	Product 6 @ 100 + 300	17	b	19	b	4	b	2	b
	Product 6 @ 133 + 400	5	b	5	b	2	b	0.25	b
	Product 6 @ 200 + 600	4	b	5	b	0	b	0	b
	Le-Mat	0	b	0	b	0	b	0	b
	P value	<0.0001		<0.0001		<0.0001		<0.0001	
	F-statistic	1747.03		179.42		75.15		91.46	
	df	4, 16		4, 16		4, 16		4, 16	
4	Untreated	292	a	400	a	234	a	294	a
	Product 7 @ 250	240	ab	115	b	147	ab	170	abc
	Product 7 @ 375	210	ab	124	b	86	bc	173	abc
	Product 7 @ 500	123	bc	66	bc	84	bc	98	bd
	Product 7 @ 250 + Product 8	154	ac	152	b	196	a	262	ac
	Product 7 @ 375 + Product 8	78	cd	37	c	43	c	61	d
	Product 7 @ 500 + Product 8	41	d	40	c	36	c	69	d
	Product 8	162	ac	160	b	155	ab	130	cd
	Le-Mat	0	e	0	d	0	d	0	e
	P value	<0.0001		<0.0001		<0.0001		<0.0001	
	F-statistic	100.21		87.90		88.83		82.73	
	df	8, 28		8, 28		8, 28		8, 28	

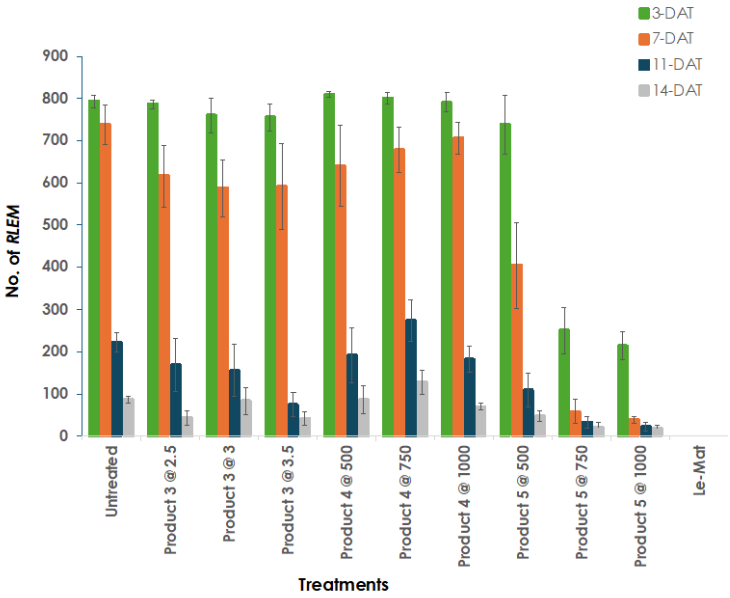
Table 3. Average plant damage scores at each sampling date and results from one-way ANOVAs comparing treatments for the four trials. Different letters indicate significantly different means at each sampling date (at the *P* < 0.05, Tukey's-*b* post hoc test).

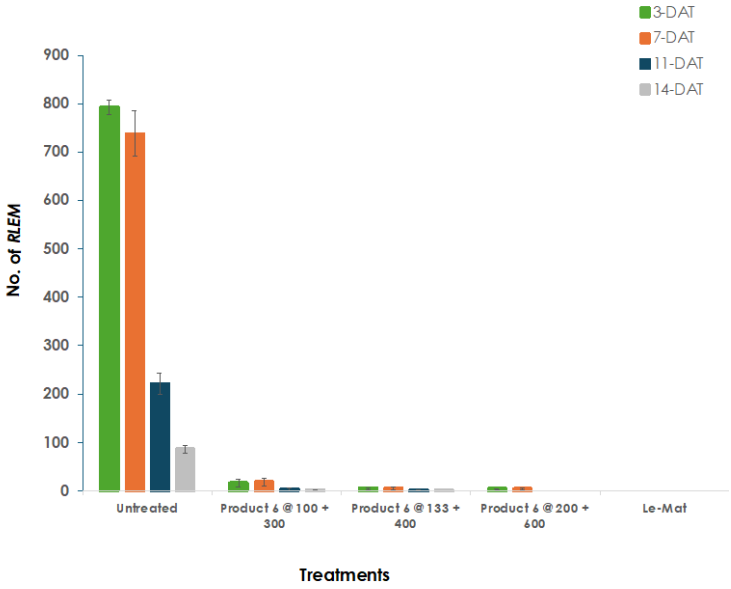
Trial No.	Treatments	3-DAT		7-DAT		10/11-DAT		14-DAT	
1	Untreated control	1.4	ab	2.1	a	3.4	a	3.8	a
	Product 1 @ 0.25	1.5	b	2.0	a	3.0	ab	3.3	a
	Product 1 @ 0.5	1.4	ab	2.1	a	2.8	ab	3.1	a
	Product 1 @ 1	1.1	bc	1.8	a	2.9	ab	3.4	a
	Product 2 @ 400	1.0	bc	1.6	a	2.3	b	2.8	a
	Product 2 @ 600	1.1	bc	1.9	a	2.5	ab	2.9	a
	Product 2 @ 800	0.9	ac	1.5	ab	2.5	ab	3.0	a
	Le-Mat	0.8	c	0.8	b	0.8	c	0.8	b
	P value	0.003		<0.0001		<0.0001		<0.0001	
	F-statistic	4.29		7.48		10.67		9.51	
	df	7, 25		7, 25		7, 25		7, 25	
2	Untreated control	1.4	a	2.1	a	3.4	a	3.8	a
	Product 3 @ 2.5	1.0	a	1.8	ab	2.6	abc	2.9	abc
	Product 3 @ 3	0.9	a	1.6	ab	2.4	abc	2.8	abc
	Product 3 @ 3.5	1.0	a	1.5	ac	2.3	abc	2.6	abc
	Product 4 @ 500	0.8	a	1.6	ab	2.8	abc	3.1	abc
	Product 4 @ 750	1.0	a	1.8	ab	3.0	ab	3.4	ab
	Product 4 @ 1000	1.0	a	1.8	ab	2.9	ab	3.4	ab
	Product 5 @ 500	1.1	a	1.6	ab	2.4	abc	2.9	abc
	Product 5 @ 750	1.3	a	1.5	ac	1.8	bd	1.9	bd
	Product 5 @ 1000	1.0	a	1.3	bc	1.4	cd	1.5	cd
	Le-Mat	0.8	a	0.8	c	0.8	d	0.8	d
	P value	0.07		0.001		<0.0001		<0.0001	
	F-statistic	1.99		4.21		6.67		6.62	

	df	10, 34		10, 34		10, 34		10, 34	
3	Untreated control	1.4	a	2.1	a	3.4	a	3.8	a
	Product 6 @ 100 + 300	0.8	a	0.8	b	0.8	b	0.8	b
	Product 6 @ 133 + 400	0.9	a	0.9	b	0.9	b	0.9	b
	Product 6 @ 200 + 600	0.8	a	0.8	b	0.8	b	0.8	b
	Le-Mat	0.8	a	0.8	b	0.8	b	0.8	b
	P value	0.026		<0.0001		<0.0001		<0.001	
	F-statistic	3.68		12.49		22.57		29.35	
	df	4, 16		4, 16		4, 16		4, 16	
4	Untreated	2.1	a	3.0	a	3.7	a	4.9	a
	Product 7 @ 250	1.9	ab	2.8	a	3.5	ab	4.5	abc
	Product 7 @ 375	1.5	bc	2.1	b	2.8	bc	3.1	de
	Product 7 @ 500	1.1	c	1.8	b	2.5	cd	3.5	ce
	Product 7 @ 250 + Product 8	1.3	c	1.9	b	2.5	cd	3.4	bde
	Product 7 @ 375 + Product 8	0.5	d	1.0	c	1.6	de	2.5	de
	Product 7 @ 500 + Product 8	0.5	d	0.9	c	1.4	e	2.1	d
	Product 8	2.0	a	3.0	a	3.9	a	4.8	ac
	Le-Mat	0.5	d	0.5	c	0.4	f	0.3	f
	P value	<0.0001		<0.0001		<0.0001		<0.0001	
	F-statistic	61.28		65.76		36.79		30.73	
	df	8, 28		8, 28		8, 28		8, 28	

Figure 10. Average number of RLEM at each sampling date comparing treatments for Trial 1 (top left), Trial 2 (top right), Trial 3 (bottom left) and Trial 4 (bottom right). Error bars represent the standard error of the mean.







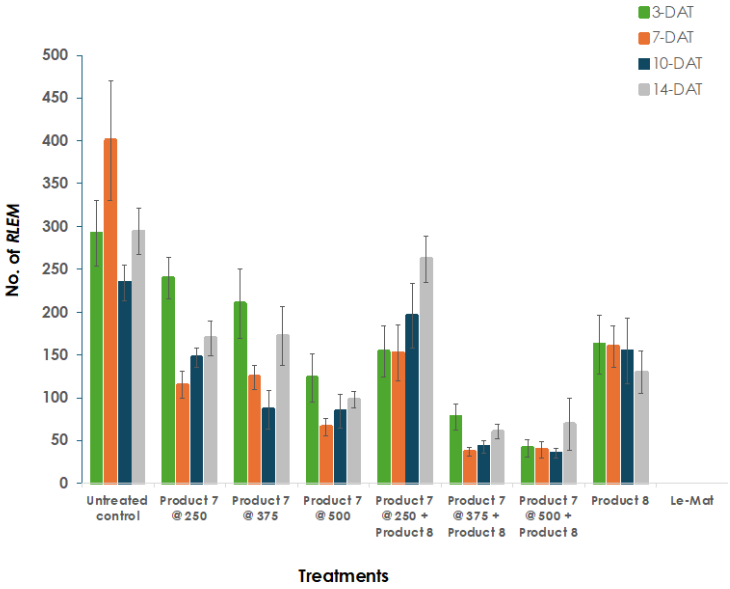
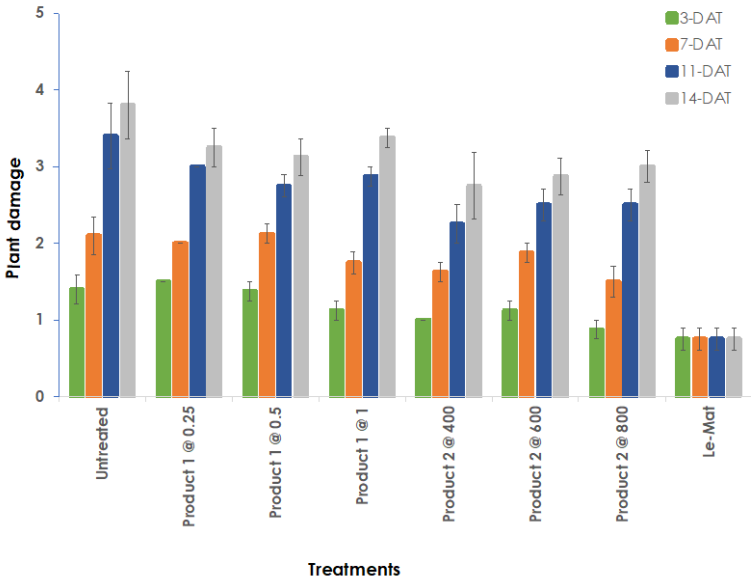
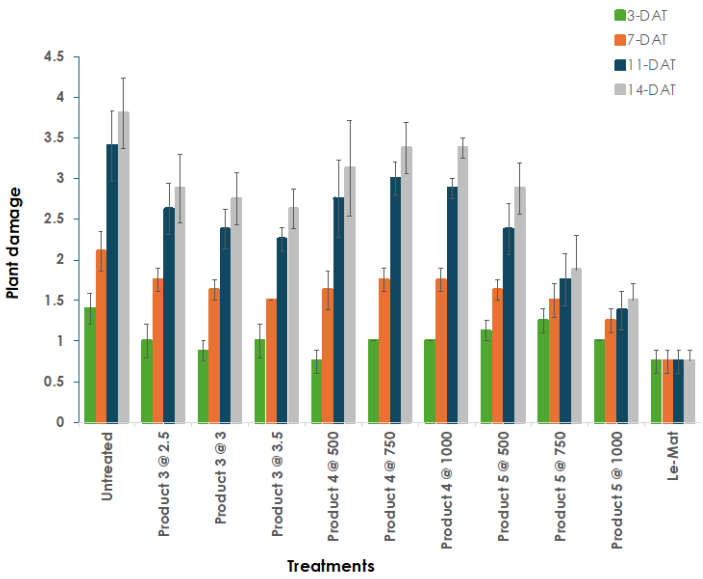
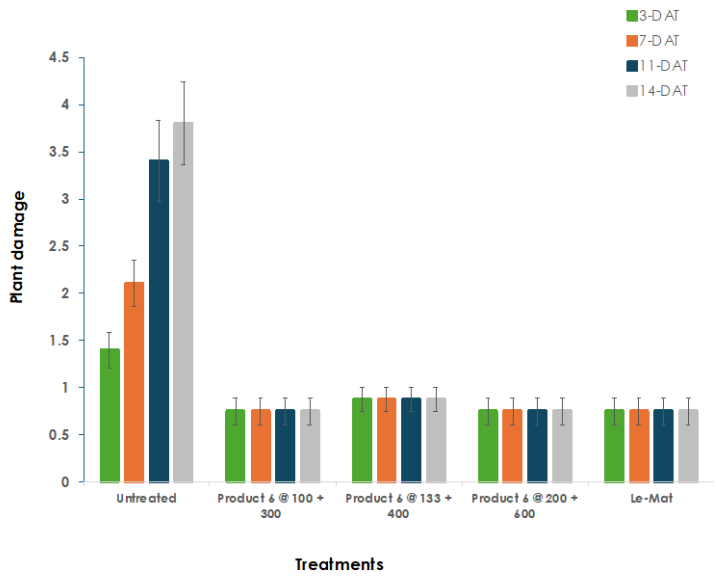
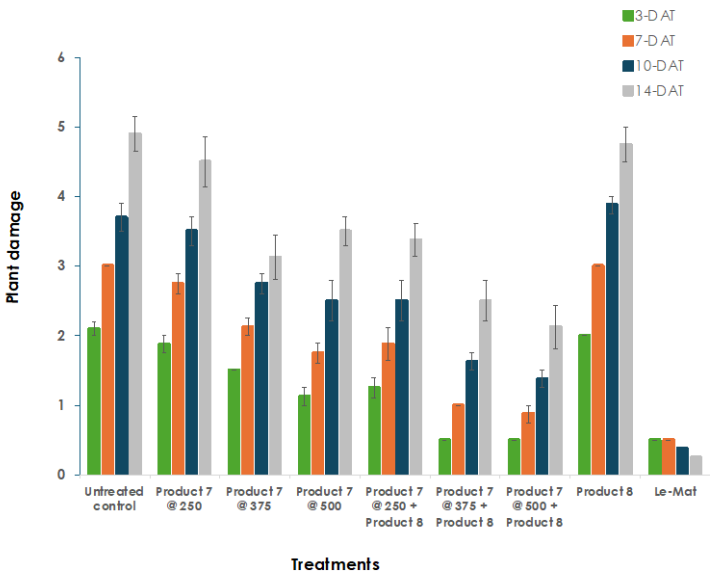


Figure 11. Average plant damage at each sampling date comparing treatments for Trial 1 (top left), Trial 2 (top right), Trial 3 (bottom left) and Trial 4 (bottom right). Error bars represent the standard error of the mean.









From these discussions, two candidate chemicals (Product A and Product B) from two different agri-chemical companies were identified and tested under field trials, which included one chemical (Product B) that was tested on pasture in the microcosm trials.

The product details tested in these trials (and the results) are to remain confidential and should not be communicated or shared outside of MLA.

4.3.2 Field trials

The microcosm testing undertaken in 2021 and 2022 identified two candidate chemicals (Product A and Product B) that indicated high levels of efficacy against RLEM and included products that the chemical companies had a genuine interest in registering against RLEM. This included one chemical (Product B) that was tested on pasture. The efficacy of these two chemicals was subsequently tested directly in two field trials in 2023. The field trials were undertaken on canola and a clover/grass-based pasture, with the pasture trial being tested specifically as part of the MLA investment. Unexpectedly, in the field trials, these two chemicals at the rates tested did not confer strong efficacy against RLEM or offer substantial protection from mite feeding when applied as foliar treatments on either canola or pasture. Similarly, these products did not confer efficacy against blue oat mites, which were also found at the pasture trial site. In the case of Product A, this could be due to the rates used in the field trials as part of this study, which were much lower than the rates tested in the microcosm trial (as determined by the relevant agro-chemical company). However, this does not explain the poor level of control achieved by Product B, given this product was tested at the same two rates as in the microcosm trial. The reason(s) for the inconsistency between the microcosm and field trial results for Product B remain unclear, although it is worth noting that the plant coverage at the pasture trial at the time of spraying was quite dense (100% coverage and between 5-15 cm in height) and there was substantial rainfall soon after the chemical treatments were applied at this site (> 50 mm of rain within 48 hours of spraying). These factors are likely to have impaired the field efficacy of Products A and B and goes some way to explaining why the conventional product (Le-Mat) achieved a lower level of control than expected in the pasture trial (based on many previous field trials where this product has been applied to control RLEM).

Follow up meetings with both agro-chemical companies were held in late December 2023 to consider all trial results and discuss next steps. We are aware that at least one of the companies has decided to continue progressing RLEM trials based on the efficacy indicated in the earlier microcosm trials.

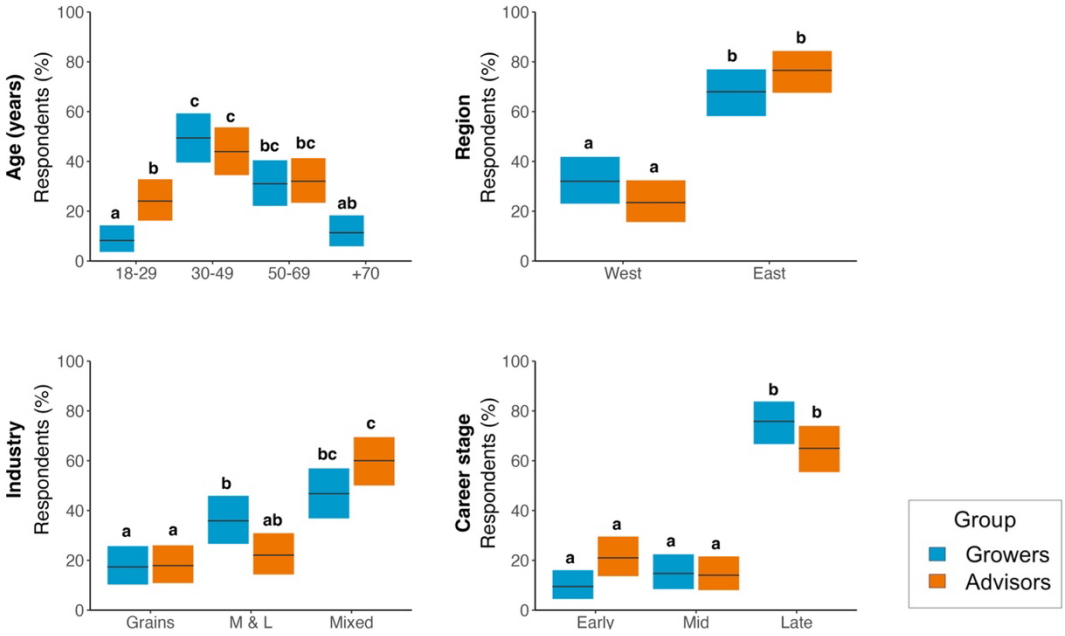
The results of both field trials conducted in 2023 are attached (commercial in confidence – not to be distributed).

4.4 Social benchmarking and extension

4.4.1 Social benchmarking

We received a total of 273 responses to the survey. Of these, 83 were removed as they were ineligible, resulting in 93 and 97 responses from growers and advisors, respectively. The frequency of responses as stratified by the age, region, industry, and career demographics is shown in Figure 12.

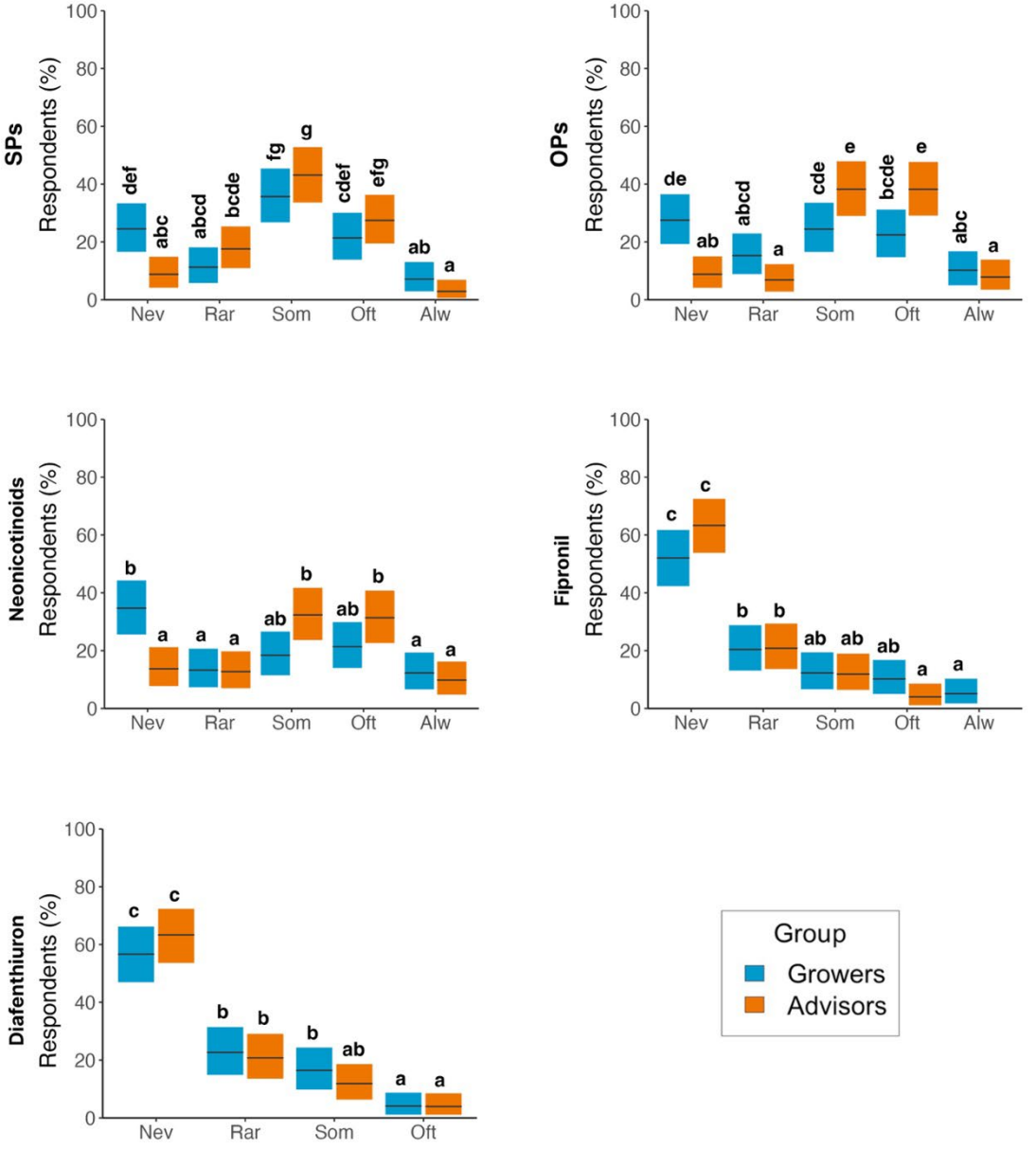
Figure 12. Frequency of responses as stratified by the age, region, industry and career stage demographics for growers (blue) and advisors (orange). The black horizontal lines represent the mean response, the coloured boxes the associated uncertainty (95% Credible Intervals), and the bold letters the statistical groups. M & L: Meat & Livestock.



Most growers and advisors were in the 30-49 and 50-69 age categories respectively, with more responses coming from young (18-29 age category) advisors as compared to young growers, and no responses coming from advisors in the *older than 70 years old* category. Most responses were provided by growers and advisors in Victoria and other eastern states as compared to responses coming from WA. Most responses provided by growers were from those belonging to the *Meat and Livestock* and *Mixed* industry categories, while most responses from advisors were from those belonging to the *Mixed* category. A large proportion of responses were from growers and advisors in the *Late* career stage category (more than 10 years of experience).

When growers were asked how often they apply foliar pesticides specifically for control of RLEM, 5% answered several times a season, 35% every year, 25% once every 2-3 years, 9% once every 4-5 years, 14% rarely (once in a 10-year period), 11% never and 1% not sure. The self-reported spraying frequencies for different chemical groups in the management of RLEM as reported by growers and advisors is summarised in Figure 13. For SPs, most responses from both growers and advisors were in the *Sometimes* category, with more growers indicating that they never apply SPs as compared to advisors. For OPs, growers' responses were similar across all categories, whereas the responses of advisors were mostly in the *Sometimes* and *Often* categories. For neonicotinoids, growers' responses were roughly similar across all categories, with the largest number of responses falling in the *Never* category – on the other hand, the responses of advisors were mostly in the *Sometimes* and *Often* categories. For fipronil and diafenthiuron, most responses from both growers and advisors belonged in the *Never* category.

Figure 13. Self-reported spray frequencies for different chemical groups in the management of RLEM as reported by growers (blue) and advisors (orange). The black horizontal lines represent the mean response, the coloured boxes the associated uncertainty (95% Credible Intervals), and the bold letters the statistical groups. Nev: Never; Rar: Rarely; Som: Sometimes; Oft: Often; Alw: Always.



For growers, the age, region, industry, and career stage demographics did not have an effect on the probability of spraying once or more times per season (Fig. 14). On the other hand, these demographics had a distinct effect on the probability that advisors would advise their clients to spray once or more times per season (Fig. 15). For example, young advisors (18-29 age category) are more likely to advice to spray than older advisors (30-49 and 50-69 age categories). Similarly,

advisors in the *West*, *Meat and Livestock* and *Mixed*, and *Early* and *Mid* categories are more likely to advise to spray than those in the *East*, *Grains*, and *Late* categories, respectively.

Figure 14. Effect of the age, region, industry, and career stage demographics on the probability that growers will spray a chemical to control RLEM once or more times per season. The black horizontal lines represent the mean response, the blue boxes the associated uncertainty (95% Credible Intervals), and the bold letters the statistical groups. M & L: Meat & Livestock.

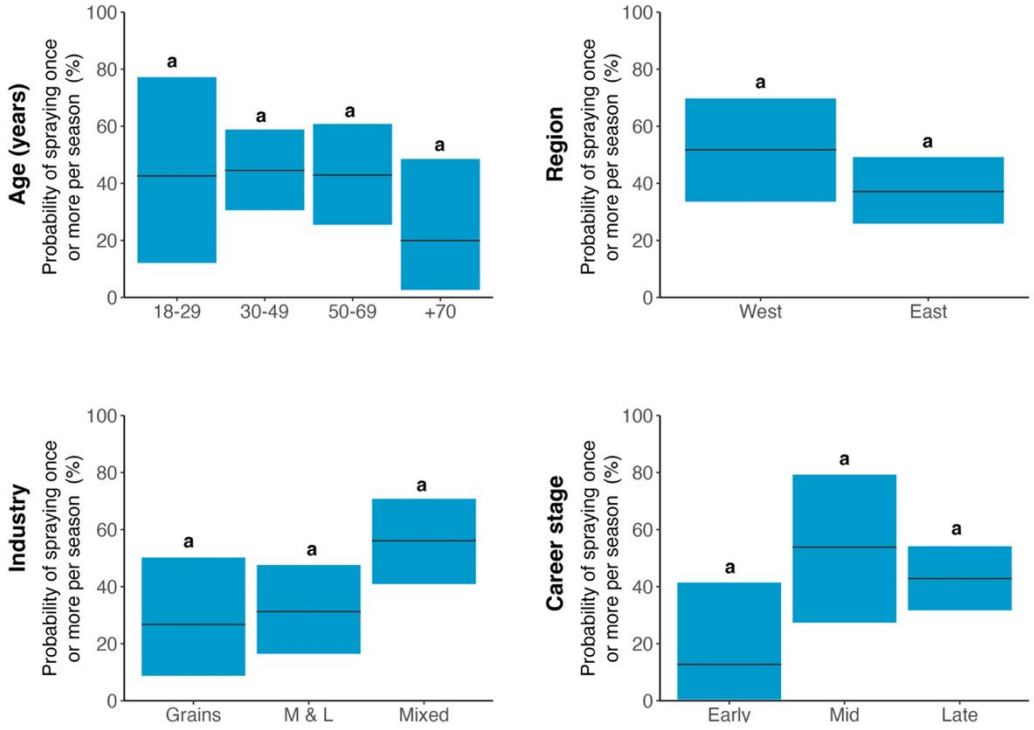


Figure 15. Effect of the age, region, industry, and career stage demographics on the probability that advisors will advise to spray a chemical to control RLEM once or more times per season. The black horizontal lines represent the mean response, the orange boxes the associated uncertainty (95% Credible Intervals), and the bold letters the statistical groups. M & L: Meat & Livestock.

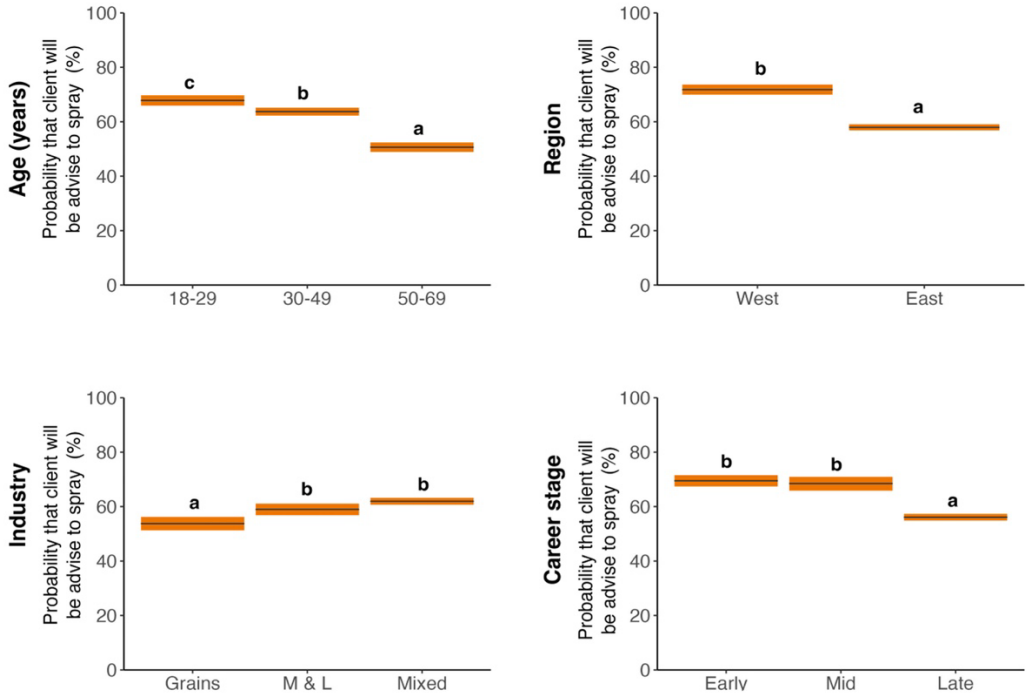
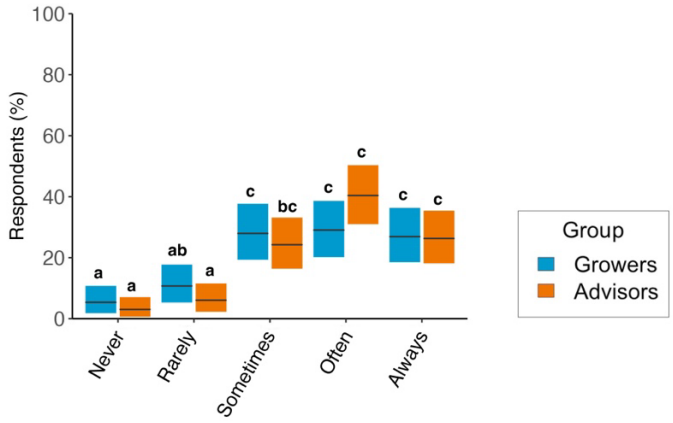


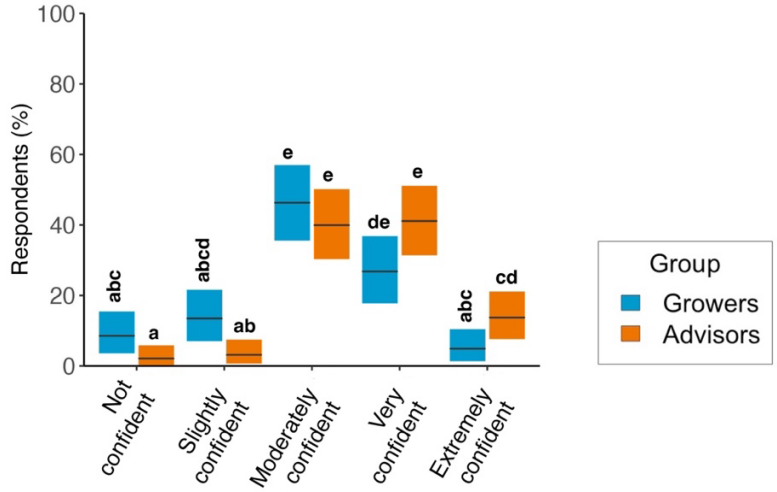
Figure 16. Growers (blue) and advisors (orange) responses when asked how often they employ an IPM mindset when making RLEM management decisions or providing advice. The black horizontal lines represent the mean response, the coloured boxes the associated uncertainty (95% Credible Intervals), and the bold letters the statistical groups.



For both growers and advisors, most responses to the question *How often do you employ an IPM mindset when making RLEM management decisions or providing advice?* fell in the *Sometimes*, *Often* and *Always* categories (Fig. 16). When making RLEM management decisions 72% of growers consider environmental factors and 77% consider paddock history. For advisors giving management support, 81% consider environmental factors and 88% consider paddock history.

For both growers and advisors, most responses to the question *How confident they were about making decisions about (growers) or providing advice on (advisors) RLEM management?* fell in the *Moderately confident* and *Very confident* categories (Fig. 17).

Figure 17. Growers (blue) and advisors (orange) responses when asked how confident they were about making decisions about (growers) or providing advice on (advisors) RLEM management. The black horizontal lines represent the mean response, the coloured boxes the associated uncertainty (95% Credible Intervals), and the bold letters the statistical groups.



To assess risk, respondents were asked:

How strongly do you agree or disagree with the following statements:

I am willing to take risks when it comes to farming.

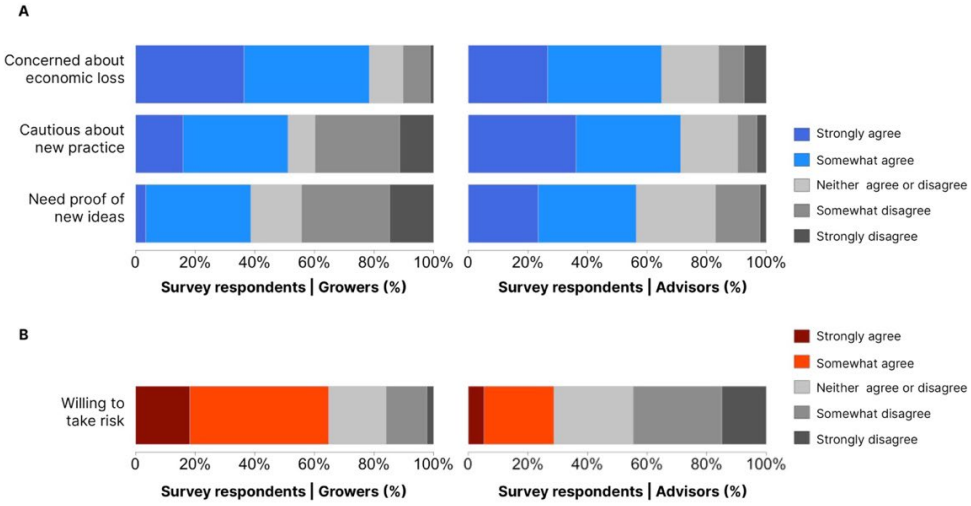
I am cautious about adopting new ideas and farm practices.

A new farm practice must be proven on other farms or trials before I will use it.

I am concerned about economic loss as a result of invertebrate pest damage.

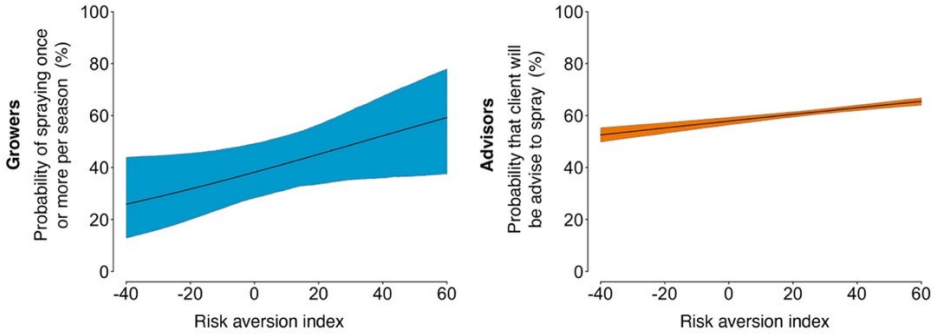
The frequency of responses to these risk questions are shown in Figure 18. Growers are most worried about economic loss, whereas advisors are most cautious about adopting new practices. As much as 60% of growers, in contrast to less than 30% of advisors, indicated that they agreed or strongly agreed with the idea of being willing to take risks when farming.

Figure 18. Growers (left bars) and advisors (right bars) responses to the questions related to risk in on-farm pest management.



The frequency of responses to the risk questions were used to develop a *Risk aversion index*. This index had a strong positive effect on the probability of growers spraying once or more per season (Fig. 19, left) and the probability of advisors advising their clients to spray once or more per season (Fig. 19, right).

Figure 19. Growers (blue) and advisors (orange) responses when asked how confident they were about making decisions about (growers) or providing advice on (advisors) RLEM management. The black horizontal lines represent the mean response, the coloured boxes the associated uncertainty (95% Credible Intervals), and the bold letters the statistical groups.



Although growers and advisors generally want to use IPM strategies, the overall knowledge about non-chemical management practices was low. Many growers and advisors could not correctly identify which chemicals RLEM has evolved resistance to (Table 4) and few respondents were aware of the insecticide resistance management strategies.

Table 4. A comparison of the percentage of growers and advisors who responded yes, no or unsure when asked whether the RLEM has evolved resistance to the chemicals listed. Cells marked in green show the correct response. fs: foliar spray; st: seed treatment.

	Growers			Advisors		
	No	Unsure	Yes	No	Unsure	Yes
Diafenthiuron[fs]	8%	70%	9%	14%	76%	4%
Fiproles[st]	11%	74%	1%	20%	74%	1%
Neonicotinoids[st]	17%	66%	3%	18%	64%	13%
Organophosphates[fs]	6%	48%	31%	6%	16%	72%
Synthetic pyrethroids[fs]	9%	46%	31%	4%	20%	71%

4.4.2 Extension Plan

Throughout the project, the RLEM online training modules have been distributed and promoted across various platforms, including Cesar Australia's social media channels. Access to all three modules is available at https://cesar-online-training.thinkific.com/, with an impressive enrolment of 137 students on Thinkific.

Our promotion efforts have leveraged popular social media channels among Australian grain growers and red meat producers, such as X (formerly known as Twitter), Facebook, and LinkedIn. Through these channels, we actively promoted project outputs, including predictive and decision-aid tools, online training modules, and updates on insecticide resistance. Project outputs have been also shared through PestFacts, as well as the communication channels of several project partners. Media releases have been dispatched on an ongoing basis to all project partners, reminding farmers of the insecticide resistance service, and encouraging them to send samples for resistance testing.
In April 2023, we expanded our outreach by launching two podcasts on the Cesar Australia Soundcloud account. These focused on the hatch timing tool and severity risk calculator, providing valuable content that was shared throughout the RLEM season.

Our project team actively participated in key industry events, presenting at several GRDC updates held across south-eastern Australia (Adelaide, Bendigo, Keith) and WA (Perth). These presentations provided crucial updates on RLEM insecticide resistance status, resistance management strategies, decision aid tools, and the social benchmarking components of the project.

Additionally, as part of the PDS project led by Agridome, there have been several extension and communication activities including webinars, field days and online workshops that have supported the sharing of project findings, RLEM decision aid tools and RLEM management advice.
The following media and communication activities have been undertaken by Cesar Australia:

2024 activities

Month, year	Activity/description	Link	Engagement
February 2024	GRDC updates in Adelaide: "Redlegged earth mite and pesticide resistance: the latest in best practice management and new decision-aid tools". Presented by Luis Mata.	https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2024/02/rlem-and-pesticide-resistance-the-latest-in-best-practice-management-and-new-decision-aid-tools	
February 2024	GRDC updates in Bendigo: "Redlegged earth mite and pesticide resistance: the latest in best practice management and new decision-aid tools". Presented by Luis Mata.	https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2024/02/rlem-and-pesticide-resistance-the-latest-in-best-practice-management-and-new-decision-aid-tools	
February 2024	GRDC updates in Wagga Wagga: "Redlegged earth mite and pesticide resistance: the latest in best practice management and new decision-aid tools". Presented by James Maino.	https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2024/02/rlem-and-pesticide-resistance-the-latest-in-best-practice-management-and-new-decision-aid-tools	
February 2024	Online guide published on Cesar Australia website: "Simple in-field test to detect pyrethroid resistance in redlegged earth mites". By Adriana Arturi and James Maino.	https://cesaraustralia.com/blog/detecting-pyrethroid-resistance-in-redlegged-earth-mites-a-simple-in-field-test/	
March 2024	RLEM benchmarking short follow up survey promoted via PestFacts newsletter, "How well do YOU know redlegged earth mite?". By Adriana Arturi.	https://cesaraustralia.us4.list-manage.com/track/click?u=e46bf4a27e954ada37ce258ac&id=ac1dd356c6&e=02f29d32e6	
March 2024	Webinar - Less Mites, More Feed: RLEM resistance, management, and decision tools. Presented by James Maino.	Available on MLA website pending approval.	
April 2024	PestFacts article: "Redlegged earth mite hatching and monitoring strategies". By Adriana Arturi and Lilia Jenkins.	https://cesaraustralia.com/pestfacts/redlegged-earth-mite-hatching-and-monitoring-strategies/	

2023 activities

Month, year	Activity/description	Link	Engagement
February 2023	GRDC updates in Adelaide: "Benchmarking attitudes to pest management and results of IPM demonstrations on RLEM control". Presented by Lizzy Lowe.		
February 2023	Insecticide Resistance Update PestFacts article.	https://cesaraustralia.com/pestfacts/insecticide-resistance-redlegged-earth-mite-update/	183 clicks
February 2023	GRDC updates in Bendigo: "Benchmarking attitudes to pest management and results of IPM demonstrations on RLEM control". Presented by Paul Umina.		
February 2023	GRDC updates in Perth: "Benchmarking attitudes to pest management and results of IPM demonstrations on RLEM control". Presented by Lizzy Lowe.		
February 2023	RLEM Training modules promoted through social media channels.		
April 2023	RLEM hatch dates and monitoring article on PestFacts.	https://cesaraustralia.com/pestfacts/redlegged-earth-mite-insecticide-resistance-testing-2023/	183 clicks
April 2023	RLEM hatch timing tool promoted through social media channels.		
May 2023	Insecticide resistance screening service promoted through: PestFacts, MLA, Agrifutures.	https://cesaraustralia.com/pestfacts/redlegged-earth-mite-insecticide-resistance-testing-2023/	96 clicks
		https://www.mla.com.au/news-and-events/industry-news/free-screening-service-to-test-for-insecticide-resistance-in-redlegged-earth-mite/	
		https://agrifutures.com.au/news/free-screening-service-	

		to-test-for-insecticide-resistance/	
May 2023	GRDC podcast: "Re-thinking management options for redlegged earth mite to help growers address insecticide resistance". By Lizzy Lowe.	https://grdc.com.au/news-and-media/audio/podcast/re-thinking-management-options-for-redlegged-earth-mite	
May 2023	RLEM decision-aid tools added to the Cesar Australia website resources page and promoted through social media channels.	https://cesaraustralia.com/resources/redlegged-earth-mite-hatch-timing-tool/	223 clicks
		https://cesaraustralia.com/resources/redlegged-earth-mite-interactive-risk-calculator/	141 clicks
		https://cesaraustralia.com/resources/timerite/	68 clicks
May 2023	RLEM decision-aid tools podcast launched.	https://soundcloud.com/cesar-australia/severity-risk-calculator	32 plays
		https://soundcloud.com/cesar-australia/hatch-timing-tool-for-redlegged-earth-mites	28 plays
July 2023	Northern Victoria PDS field day. Live demonstration of bug counts and pasture measurements for project "Less Mites, More Feed".		6 producers in attendance
July 2023	ABC radio interview with Paul Umina: "Redlegged earth mite insecticide resistance".		
August 2023	Perennial Pasture Systems winter farm tour with James Maino on RLEM identification, management, and seasonal risk.		
August 2023	Online pasture insect and mite identification workshop as part of the PDS project. 28 producers, 7 advisers, 4 Landcare facilitators. The remainder of the attendees included development officers, researchers, and students.		40 attendees
August 2023	GRDC updates in Keith (Online): "Using resistance surveillance,		

	and social benchmarking to improve redlegged earth mite management". Presented by Lizzy Lowe.		
September 2023	GRDC Southern News: "Considering Timerite in spring for RLEM control".		
September 2023	PestFacts: "Considering Timerite in spring for RLEM control".	https://cesaraustralia.com/pestfacts/considering-timerite-in-spring-for-redlegged-earth-mite-control/	206 clicks
November 2023	Recap, results, discussion: Spring Webinar – Agridome's "Less mites, More Feed".		13 producers in attendance
December 2023	Crop Protection Forum: "Managing resistance in the redlegged earth mite". Presented by Luis Mata.		

2022 Activities

Month, year	Activity/description	Link	Engagement
March 2022	PestFacts article: "Predicting redlegged earth mite hatch dates".	https://cesaraustralia.com/pestfacts/rlem-hatch-dates_2022/	650 clicks
March 2022	Webinar on mite identification and management for NSW Local Land Services central and central western.	https://www.youtube.com/watch?v=LmZ8ZqgA60c	
June 2022 – RLEM resistance screening service promoted	Agrifutures article – "Free screening service to test for insecticide resistance in the RLEM".	https://agrifutures.com.au/news/free-screening-service-to-test-for-insecticide-resistance-in-the-redlegged-earth-mite/	
	GRDC article – "Growers urged to test redlegged earth mite for resistance".	https://groundcover.grdc.com.au/weeds-pests-diseases/pests/growers-urged-to-test-redlegged-earth-mite-for-resistance	
	Mirage Latest news – article titled "Growers urged to test redlegged earth mite for resistance".	https://www.miragenews.com/growers-urged-to-test-redlegged-earth-mite-for-811063/	

	Grain Central – article titled "Growers urged to test redlegged earth mite for resistance"		
	GRDC Southern News – article titled "Growers urged to test redlegged earth mite for resistance".		
	GRDC Northern News – article titled "Growers urged to test redlegged earth mite for resistance".		
August 2022	2022 - Stock Journal (SA) article titled "Staying on top of RLEM".		
October 2022	Third and final RLEM online training module published on Thinkific platform.	https://cesar-online-training.thinkific.com/	

2021 Activities

Month, year	Activity/description	Link	Engagement
February 2021	PestFacts article: "New project investigating insecticide resistance and control options for RLEM".	https://cesaraustralia.com/blog/new-redlegged-earth-mite-project/	316 clicks
April 2021	PestFacts early season webinar – RLEM resistance update.	https://www.youtube.com/watch?v=S5YR5bXumM0&t=1153s	109 views
May 2021	RLEM management tools webinar.	https://www.youtube.com/watch?v=9A8jO7nAeuY	134 views
May 2021	PestFacts article: "NEW RLEM hatch timing tool".	https://cesaraustralia.com/pestfacts/new-redlegged-earth-mite-hatch-timing-tool/	513 clicks
June 2021	MLA article: "Free screening service to test for insecticide resistance in the RLEM".	https://www.mla.com.au/news-and-events/industry-news/free-screening-service-to-test-for-insecticide-resistance-in-the-redlegged-earth-mite/	
July 2021	PestFacts article: "Redlegged earth mite management survey".	https://cesaraustralia.com/blog/cesar-australia-	330 clicks

		redlegged-earth-mite-survey/	
July 2021	First RLEM online module published on the Thinkific platform.	https://cesar-online-training.thinkific.com/	
August 2021	PestFacts article: "What is the cost of pyrethroid resistance"?	https://cesaraustralia.com/blog/what-is-the-cost-of-pryrethroid-resistance-for-redlegged-earth-mites/	178 clicks
September 2021	Redlegged earth mite IPM demonstration trials – webinar.	https://www.youtube.com/watch?v=xyQkQF-ms4A	104 views
September 2021	PestFacts article: "When is it time to consider Timerite?".	https://cesaraustralia.com/pestfacts/timerite_2021/	429 clicks
October 2021	Paul Umina the research outputs from this work in his presentation at the Crop Protection Forum in Launceston.		
December 2021	Second RLEM online module published on the Thinkific platform	https://cesar-online-training.thinkific.com/	

5. Conclusion

5.1 Key findings

Resistance surveillance conducted between 2021 and 2023 continued to detect resistance in RLEM throughout WA, SA and Victoria. There was a significant increase in detections of insecticide resistance in RLEM populations in eastern Australia during this surveillance period, particularly within SA. Resistance was detected in several new regions including the mid-north and south east coast of SA. Additionally, several new OP resistant populations were detected in Victoria in the north central region and in Minimay in the Wimmera region. RLEM resistance appears to be increasing in WA as well, with new resistant populations being detected each year. In 2022, RLEM resistance to OPs was detected for the first time in the southern coastal regions of WA.

Most of the resistant populations (over 80%) detected in eastern Australia possessed resistance to OPs, while 48% possessed resistance to SPs. This can have important implications for ongoing resistance management in the field, due to differences in response between chemical groups. For instance, current field rates of OP chemicals may still provide some level of control against OP resistant RLEM due to low resistance in OPs, while treatments with SPs on SP resistant mites will only lead to rapid increases in the frequency of the *kdr* resistant allele, causing higher levels of SP resistance, and little or no control (Arthur et al. 2021).

Of the 49 populations collected and screened as part of this project, five populations were found to possess OP resistance, two with SP resistance, and four with dual resistance to both OPs and SPs. This included the population in the north central region of Victoria and populations in the SA regions where RLEM resistance was detected for the first time (mid-north and south-east coast). The other populations where resistance was detected from these collections were from Kangaroo Island and the Fleurier Peninsula.

The testing of novel MoA and biological products under microcosm and bioassay trials ruled out many products as having potential for RLEM control, identifying only two candidate chemicals (Product A and Product B) that indicted high efficacy and were products that the chemical companies had a genuine interest in registering against RLEM. Field testing of these two products, however, did not show the same level of efficacy. Unexpectedly, Products A and B at the rates tested in the field trials did not confer strong efficacy against RLEM or offer substantial protection from mite feeding when applied as foliar treatments on canola and pasture. In the case of Product A, this could be due to the rates used in the field trials as part of this study, which were much lower than the rates tested in the microcosm trial (as determined by the relevant agro-chemical company). However, this does not explain the poor level of control achieved by Product B, given this product was tested at the same two rates as in the microcosm trial. The reasons for the inconsistency between the microcosm and field trial results for Product B remain unclear, although it is worth noting that the plant coverage at the pasture trial at the time of spraying was quite dense and there was substantial rainfall soon after the chemical treatments were applied at this site. These factors are likely to have impaired the field efficacy of Products A and B and go some way to explaining why the conventional product (Le-Mat) achieved a lower level of control than expected in the pasture trial.

Caution is always needed when translating microcosm trials to the field as the conditions of plants grown under semi-field microcosms trials are not representative of those experienced by crop plants in the field and the impact of chemicals can vary. That being said, prior to this project, we have found microcosm results to be quite indicative of field performance against a wide range of arthropod pests, including RLEM and blue oat mites. We held follow up meetings with both agro-chemical companies in late December 2023 to consider all trial results and discuss next steps. We are aware that at least one of the companies has decided to continue progressing RLEM trials based on the efficacy indicated in the earlier microcosm trials.

Regarding the hatch timing tool, we were able to successfully predict the hatch timing of RLEM, which will enhance early season monitoring of this establishment pest under variable climates. We also updated the TIMERITE® strategy for RLEM control under changing climates with key findings including: (1) climatic variables enhance diapause prediction and significantly improved the accuracy of predicting diapause onset in RLEM, compared to using only daylength and growing season length as in the original TIMERITE® model; (2) climate change impacts TIMERITE® efficacy with changing temperature and rainfall patterns over the past three decades reducing the effectiveness of the original TIMERITE® model, leading to lower control efficacy; (3) modifying the TIMERITE® strategy to include dynamic climate data and a dynamically adjusted control timing (rather than a fixed offset from the predicted diapause date) resulted in higher and more stable control efficacies across diverse environments and years.

The analysis of social research data revealed insights into current knowledge and attitudes on insecticide resistance management, encompassing both growers and advisors. Most respondents were from mixed farming and meat and livestock production. The study provided insights into the spray frequency of different chemical groups used by producers and recommended by advisors. Notably, most participants adopted an IPM mindset for RLEM management. Producers and advisors

exhibited distinct risk attitudes, with economic impacts a primary concern for producers and advisors, emphasising the importance of trialling new practices.

The gained insights from this social benchmarking activity will play an important role in enhancing communication and extension outputs. For instance, there is a recognised need to boost awareness regarding the RLEM Resistance Management Strategy (RMS) and the resistance status of different chemicals, as this information was not widely known among respondents. The forthcoming outputs will focus on increasing awareness about the identification and biology of different mites and highlighting the longer-term implications of resistance.

Cesar Australia and MLA have been working closely together to successfully produce extension and communication outputs for the project, including the development of online training modules and articles. Additionally, the PDS project has served and will continue to serve as an opportunity to showcase and promote key outputs, such as the comprehensive RLEM lifecycle and biology, resistance management strategies, and decision aid tools.

5.2 Benefits to industry

Project findings indicate significant challenges in the current and long-term viability of chemical control options to manage RLEM due to increasing emergence of insecticide resistance developing across the southern growing regions of Australia and lack of alternative chemical options. Furthermore, the difficulty in finding new chemical MoA groups effective against RLEM have proved challenging. This, along with the spread of insecticide resistance to SPs and OPs, has major implications for how to manage this pest in the future. Pro-active resistance management of RLEM by producers and advisors will be key to delaying the spread and further evolution of resistance and ensuring that the limited chemical options available for RLEM remain effective into the future. This can be achieved by avoiding unnecessary chemical treatments, rotating between chemical groups, strategic spraying, and the use of biological and cultural control strategies, all of which are advocated in the current National RLEM RMS. Importantly, the new knowledge gained through this investment will be fed into the new version of the RLEM RMS, ensuring it provides the best practice recommendations for RLEM control.

The hatch timing tool will increase the monitoring precision of RLEM and thus minimise pest risk. Monitoring is a labour-intensive task, so this increased precision will help to ensure monitoring resources are used to their greatest effect. Ineffective pesticides used before mite hatching can be more easily avoided by checking local hatch status. Similarly, early sown pastures may be able to outgrow pest risk if significant plant growth can occur prior to RLEM hatch.

The updated TIMERITE® model offers significant benefits to the red meat industry by minimising RLEM impacts, improving pasture productivity and quality, reducing pesticide use and input costs, and enabling adaptation to climate change. These improvements contribute to enhanced profitability for livestock producers, improved animal welfare, and more sustainable production practices. Furthermore, the project's focus on integrated pest management and minimised chemical residues ensures access to premium markets with stricter quality standards. By incorporating dynamic climate considerations and optimising control timing, the modified TIMERITE® model strengthens the resilience and long-term sustainability of the red meat industry.

The benchmarking research has revealed key insights into (1) current knowledge and attitudes on insecticide resistance management and (2) the spray frequency of different chemical groups used by growers and recommended by advisors. Notably, most participants adopted an IPM mindset for

RLEM management. Growers and advisors exhibited distinct risk attitudes, with economic impacts a primary concern for growers and advisors emphasising the importance of trialling new practices. The insights gained from this social benchmarking activity will play an important role in enhancing communication and extension outputs. For instance, there is a recognised need to boost awareness regarding the RLEM RMS and the resistance status of different chemicals, as this information was not widely known among respondents.

Our Producer Demonstration Site project 'Less Mites, More Feed' is currently operating at four sites across two regions in Victoria. The PDS is being conducted in collaboration with and benefiting 15 core producers (representing 28,000 ha of managed land, 86,000 sheep, and 3,000 cattle) and 93 observer producers (representing over 150,150 ha of managed land, over 505,000 sheep, and 15,000 cattle). Over the next couple of years, extension and communication activities will support the PDS project in sharing findings with core and observer producers, as well as with the broader industry. A live demonstration of data collection as part of a field day with core producers at the demonstration sites and a webinar showcasing year 1 results have been part of our extension activities. Looking ahead, 2024 will see data collections at years 2 and 3 sites and regular engagement with core and observer producers.

Forthcoming outputs – including a peer-reviewed article led by Lizzy Lowe entitled *Understanding growers and advisors knowledge and attitudes towards redlegged earth mite (Halotydeus destructor) to improve insecticide resistance management in Australia*, as well as online training modules and articles – will benefit the industry by increasing awareness about the identification and biology of different mites and highlighting the longer-term implications of resistance.

6. Future research and recommendations

RLEMs are a significant pest of pasture, affecting establishment, production and profitability for red meat producers in southern Australia. The increasing emergence of insecticide resistance across growing regions of southern Australia raises concerns for the long-term viability of chemical control for this pest in this industry. Additionally, finding new, alternative chemical options that are efficacious against RLEM has proved challenging. There is a need for a revaluation of management options for this pest and future management should address resistance issues effectively and consider new options for RLEM suppression and control.

Management strategies to minimise resistance

Future management of RLEM should aim to reduce the use of chemicals to limit selection pressures and decrease the risk of further local resistance evolution. Specific recommendations to minimise RLEM pressure and resistance include:

- Utilising decision-aid tools to increase confidence in RLEM risks and facilitate pro-active control practices, including the strategic use of TimeRiteâ as part of the overall management strategy.
- Keeping pastures short in spring; where possible, graze to < 1.4 t/ha feed on offer.
- Avoiding pre-emergence/bare earth sprays, particularly before RLEM hatching.
- Using insecticide seed treatments when mite pressure is predicted to be medium or high during seedling establishment.

- When using insecticides, following resistance management recommendations, including the rotation of chemical groups.
- Controlling weeds (especially capeweed and medics) in and around the paddock, as these are hosts for RLEM.
- Sowing at a higher seeding rate to account for RLEM feeding damage.
- Sowing earlier in the season, if possible, so that the crop may become established before RLEM hatching.
- Considering rotations with crops that are not favoured by RLEM (e.g. cereals).

Ongoing resistance surveillance

Ongoing resistance surveillance to monitor the distribution and levels of field resistance is crucial to identify emerging resistance issues. Additionally, understanding the incidence, patterns of spread, and current distribution and nature of resistance is also important for the RLEM-RMS. In addition to OPs and SPs, it is important to explore any arising potential resistance to neonicotinoids in RLEM, particularly given the substantial selection pressure for resistance through the widespread use of seed treatments in southern Australia. Providing producers and advisors with resistance testing services also allows them to be informed of any resistance present in their paddocks, allowing them to implement effective resistant management strageties and improve management outcome to ensure effective pest control in the future.

Continue to explore novel MoA chemicals

Insecticides will likely continue to play an important role in RLEM control, however, there are only currently six registered chemical mode of groups for RLEM control; organophosphates (Group 1B), pyrethroids (Group 3A), neonicotinoids (Group 4A), fiproles (Group 2B), diafenthiuron (Group 12A) and isoxazolines (Group 30) (APVMA 2024). Of these growers rely heavily on the first three (Umina et al. 2019), with the latter three only being registered for use in canola. With the increasing emergence of resistance to OPs and SPs, control options are becoming further limited particularly in pastures where foliar sprays are commonly used. Additionally, rotations between insecticide groups are a key component of the RLEM RMS. Therefore, it is important to continue to explore and support any novel MoA and biological products being considered for RLEM control and registration.

Adoption of the RMS

It will be critical to ensure that the National RLEM RMS (https://grdc.com.au/resources-and-publications/all-publications/factsheets/2018/06/resistance-management-strategy-for-the-redlegged-earth-mite-in-australian-grains-and-pastures) is continually updated with the latest research and best management practice recommendations. It is recommended that the RLEM RMS is extensively promoted to increase awareness and adoption of its recommendations by meat and livestock producers and advisors. The individual actions of producers and advisers who are actively involved in managing RLEM will play a substantial role in minimising the evolution and spread of resistance, and adoption of the RMS will be paramount to this.

Extension and communications of research findings

Facilitating the extension of research findings holds a crucial role in advancing industry knowledge and fostering adoption in future initiatives addressing RLEM resistance and control. Education is a key component, empowering producers and advisers to confidently adopt new resistant management strategies and decisively move away from control strategies that increase the risk of resistance evolving in RLEM and other pests. This would involve comprehensive education and training, which could cover aspects such as the RLEM lifecycle, resistance management options, critical monitoring periods, and identification of different mite pests. This can be achieved through

dynamic platforms such as industry presentations, newsletters, media releases, websites, blog articles and extension workshops.

Cross-industry cooperation
Given the cross-industry nature of insecticide resistance in RLEM, greater involvement of other industries impacted by RLEM will lead to more coordinated and better outcomes for growers. Resistance management strategies also need to account for the different selection pressures across the different industries impacted by RLEM. It is recommended that MLA continue to work in collaboration with other industries impacted by RLEM to improve the management of RLEM and reduce its significant current economic impact.

7. References

APVMA. 2024. Public Chemical Registration Information System Search. https://portal.apvma.gov.au/pubcris [08 May 2024].

Arthur A, Maino J, Hoffmann A, Jasper M, Lord A, Micic S, Edwards O, van Rooyen A, Umina P. 2021. Learnings from over a decade of increasing pesticide resistance in the redlegged earth mite, *Halotydeus destructor* (Tucker). Pest Management Science 77: 3013–3024.

Baker AS. 1995. A redescription of *Halotydeus destructor* (Tucker) (Prostigmata: Penthaleidae), with a survey of ontogenetic setal development in the Superfamily Eupodoidea. International Journal of Acarology 21: 261-282.

Edwards O, Walsh T, Metcalfe S, Tay W, Hoffmann A, Mangano P, Lord A, Micic S, Umina P. 2018. A genomic approach to identify and monitor a novel pyrethroid resistance mutation in the redlegged earth mite, *Halotydeus destructor*. Pesticide Biochemistry and Physiology 144: 83-90.

Kirkland L, Pirtle E, Umina P. 2018. Responses of the Russian wheat aphid (*Diuraphis noxia*) and bird cherry oat aphid (*Rhopalosiphum padi*) to insecticide seed treatments in wheat. Crop and Pasture Science 69: 966-973.

Kirkland LS, Chirgwin E, Ward SE, Congdon BS, van Rooyen A, Umina PA. 2023. P450-mediated resistance in *Myzus persicae* (Sulzer) (Hemiptera: Aphididae) reduces the efficacy of neonicotinoid seed treatments in *Brassica napus.* Pest Management Science 79: 1851-1859.

McDonald G, Umina PA, Macfadyen S, Mangano P, Hoffmann AA. 2015. Predicting the timing of first generation egg hatch for the pest redlegged earth mite *Halotydeus destructor* (Acari: Penthaleidae). Experimental and Applied Acarology 65: 259-276.

Umina PA, McDonald G, Maino J, Edwards O, Hoffmann AA. 2019. Escalating insecticide resistance in Australian grain pests: contributing factors, industry trends and management opportunities. Pest Management Science 75: 1494–1506.