Science Behind the Resistance Management Strategy for the redlegged earth mite (*Halotydeus destructor*) in Australian grains and pastures

First edition developed by the National Insecticide Resistance Management (NIRM) working group of the Grains Pest Advisory Committee (GPAC), with current revisions made under GRDC investments CES2010-001RTX and UOM1906-002RTX

Contributing authors: Assoc Prof Paul Umina (Cesar Australia and The University of Melbourne), Prof Ary Hoffmann (The University of Melbourne), Dr Garry McDonald (The University of Melbourne), Dr Owain Edwards (CSIRO), Peter Mangano (formerly DPIRD WA), Dr Melina Miles (QDAF), Greg Baker (SARDI), Geoff Cornwell (FMC), Prof Stephen Powles (UWA), Dr Nancy Schellhorn (CSIRO), Leo McGrane (Cesar Australia), Dr James Maino (Cesar Australia), Svetlana Micic (DPIRD WA), Dr Aston Arthur (Cesar Australia) and Dr Luis Mata (Cesar Australia)

Special thanks to Adriana Arturi (Cesar Australia), Dr James Ridsdill-Smith (CSIRO), Warwick Nightingale (Delta Agribusiness), Annabel Clouston (Cesar Australia), Sally Ceeney (Ceeney Agricultural Consultants), Ken McKee (Syngenta Crop Protection), Craig Davis (Crop Consulting Services), Chris Davey (Next Level Agronomy), Dr Leigh Nelson (GRDC), Dr Lizzy Lowe (Cesar Australia), Rob Vitelli (Syngenta Australia), the CropLife Australia Expert Committee on Insecticide Resistance and the Grains Research & Development Corporation

First edition: April 2015

Current edition: October 2024

Background information

The redlegged earth mite (RLEM), *Halotydeus destructor*, is a major threat to a variety of Australian crops and pastures, with canola, lupins and legume seedlings the most susceptible to attack. RLEM are also a pest of several vegetable crops, while weeds (particularly capeweed) can act as important hosts. Mite feeding can lead to distortion or shrivelling of leaves and affected seedlings may die at emergence when mite populations are high.

The use of chemicals to target RLEM in grain crops and pastures continues to be the most common control strategy in Australia, placing strong selection pressure on the evolution of resistance. Resistance to synthetic pyrethroids (SPs), including bifenthrin and alpha-cypermethrin, is common across large parts of the Western Australian grainbelt and in South Australia (including Kangaroo Island, the Fleurieu Peninsula, and the southeast and mid-north regions). Resistance to organophosphates (OPs), including omethoate and chlorpyrifos, can be found in regions of Western Australia, South Australia, and most recently, Victoria. Some populations of RLEM in Western Australia and South Australia have been found to display dual resistance to both SPs and OPs. At present, there is no confirmed resistance to neonicotinoids in Australia.

To maintain the efficacy of current chemical options, growers and advisers can implement resistance management strategies that delay the development of further resistance. Chemicals within a specific chemical group usually share a common target site within the pest and thus share a common mode of action (MoA). A key aim of RLEM resistance management is to minimise the selection pressure for resistance to the same chemical group across consecutive mite generations.

Table 1. Background information on the redlegged earth mite

Attribute	**What is known about RLEM?**	**References**	**Knowledge gaps**
Economic importance to grains	• RLEM is a major pest of pastures and grain crops, particularly at seedling establishment. • Current and potential economic losses to the grains industry are considerable. • Economic impact varies across years.	Ridsdill-Smith 1997; Ridsdill-Smith *et al.* 2008; Ridsdill-Smith *et al.* 2013; Murray *et al.* 2013.	• Models to forecast intensity of seasonal outbreaks within paddocks and across regions. • Yield impacts based on crop, variety, climate, and pest pressure. • Updated economic analysis of impact.
Mode of reproduction	• In Australia RLEM reproduce sexually (diplodiploid). • Sperm transfer is indirect. • Adult sex ratio is female biased.	Weeks *et al.* 1995; Ridsdill-Smith 1997.	

Life cycle (incl. # generations)	• RLEM typically completes three generations per season (occasionally a fourth generation is produced). • Mites are typically active from late April until early November. • The summer is passed as a diapausing egg in the cadaver of a female mite on the soil surface. The majority of diapause eggs are produced in spring. • Temperature, daylength, and moisture all impact the onset of diapause. • TimeRite® has been updated to reflect shifts in climate over the past two decades and is an effective tool to reduce mite populations in spring. • Cryptic diapause eggs that lack the visibly darker chorion can persist over summer conditions, though with lower success than typical diapause eggs. • Autumn rainfall, accompanied by cool temperatures (range <16°C to <20.5°C) is required to break summer dormancy and commence egg hatch. Temperature requirements for egg hatch vary across Australian RLEM populations based on location.	Wallace 1970; Ridsdill-Smith 1997; Ridsdill-Smith and Annells 1997; Umina & Hoffmann 2003; Ridsdill-Smith *et al.* 2005; McDonald *et al.* 2015; Cheng *et al.* 2018a; Maino *et al.* 2024	• Accurate phenological predictions across the country of conditions leading to diapause and diapause breaking. • The point during development where the production of diapause is triggered, and whether this process is reversible (e.g. through sudden cool wet conditions in late spring). • Contribution of bet hedging strategy (diapause/non diapause egg production) to the success of RLEM across Australia. • The role of cryptic diapause eggs and the triggers that led RLEM to produce them.
Crop hosts	• Very broad host range. Includes pasture legumes, grasses, grain crops, vegetables and cut flowers. • Crops commonly attacked include canola, wheat, barley, oats, lupins, sunflower, faba beans, field peas, poppies, lucerne and vetch. • Compensation for RLEM damage can occur in crops including canola, highlighting importance of economic thresholds. • Mites are able to adapt to host plants within and between generations.	Ridsdill-Smith 1997; Ridsdill-Smith *et al.* 2008; Robinson & Hoffmann 2001; Umina & Hoffmann 2004; Ridsdill-Smith *et al.* 2013; Arthur *et al.* 2015; Cheng *et al.* 2018b; McDonald *et al.* 1995	• Economic thresholds for crops under different field scenarios. • Uncertainty of population abundance (carry-over) following varying crop rotations and pasture species compositions. • Lack of mite-tolerant crop varieties.

Non-crop hosts	• Many weeds, especially broad-leaved weeds such as capeweed (*Arctotheca calendula*), plantain (*Plantago spp.*) and bristly ox-tongue (*Helminthotheca echioides*). • Microflora can be feed upon by early stage mites.	Ridsdill-Smith 1997; MacLennan *et al.* 1998; Umina & Hoffmann 2004; Ridsdill-Smith *et al*. 2008; Ridsdill-Smith *et al.* 2013.	• There remains some uncertainty of the importance of microflora (e.g. algae) for the development of early life stages.
Distribution	• Likely origin from the Cape Town region, South Africa, where related species also occur. • Locally, southern Australia only; very common across all grain growing regions in southern WA, SA, Tasmania and Victoria. Present in southern NSW (upper distribution limit around Dubbo). Not present in Qld; distribution limits relate to aridity and seasonality. • Geographic range shifts evident in last few decades in eastern Australia through an increased ability to tolerate colder extremes and hotter and drier conditions.	Wallace & Mahon 1971; Robinson & Hoffmann 2001; Hill *et al.* 2012; Hill *et al.* 2013.	• Involvement of recent evolutionary changes versus recent climate change in accounting for changes in distribution.
Dispersal/movement	• In winter grain crops and pastures, RLEM disperse via locomotory movement (walking). This is usually only tens of metres in a mite's lifetime and can be directional, perhaps involving an olfactory response to favourable/unfavourable host plants. • Longer-range dispersal is thought to occur during the summer via the airborne movement of diapause eggs in summer dust storms. Eggs may also be dispersed on soil adhering to livestock and farm machinery and through transportation of plant material particularly fodder/hay during periods of drought. • Genetic analysis shows some differentiation between eastern and western Australia and within these areas, with ongoing gene flow across regions of Australia likely.	Ridsdill-Smith 1997; Ridsdill-Smith *et al.* 2008; Weeks *et al.* 2000; Hill *et al.* 2016; Yang *et al.* 2020.	• Some uncertainty of gene flow and long-distance dispersal capacity on a national scale. • Long distance dispersal may be better quantified with modern, high resolution molecular methods.

Feeding behaviour	• Sucking pest; mites make a hole approximately 3*um* in diameter and cell contents are sucked out using a pharyngeal pump. • RLEM tend to feed in aggregations (e.g. 30-40 individuals) as they are attracted to plant volatiles realised as a result of mite feeding. • RLEMs spend the majority of their time on or near the soil surface, only moving up onto plants to feed. • In grains crops, RLEM cause most damage at the seedling establishment period. Seedling canola is particularly susceptible. • In pastures, RLEM feeding causes seedling mortality, overall reductions in vegetative production, a loss of palatability and nutritive value of plants for livestock and reduced seed set of legumes during spring flowering.	Gaull & Ridsdill-Smith 1996; Ridsdill-Smith 1997; Ridsdill-Smith and Pavri 2000; Arthur *et al.* 2013; Ridsdill-Smith *et al.* 2013.	
Chemical controls	• Chemicals remain the key option for RLEM control in grains and other industries. • There are approximately 250 insecticide products registered in Australia against RLEM, from only six registered chemical groups; organophosphates (OPs), synthetic pyrethroids (SPs), neonicotinoids, fiproles, diafenthiuron and isoxazolines. • Growers primarily use three chemical groups - OPs (e.g. dimethoate), SPs (e.g. alpha-cypermethrin) and neonicotinoids (e.g. imidacloprid). • Fiproles (seed treatment) and diafenthiuron (foliar spray) have been registered to control RLEM in canola for several years but are not used widely. • Isoxazoline is a seed treatment only recently registered in canola. • Warmer temperatures increase chemical tolerance in RLEM compared with cooler conditions, which may be	Umina 2007; Ridsdill-Smith *et al*. 2008; Umina *et al.* 2019; Thia *et al.* 2022; APVMA 2023.	• Need for alternative chemistries, especially in pastures and lucerne, and ideally selective options (as available in cotton and horticulture). • Economic spray thresholds for grain crops.

	useful in parameterising models of RLEM control under an increasingly warm and more variable climate. • Hatch dates of RLEM can now be predicted, which could assist growers with spray decisions. The online hatch timing tool uses local climatic data to predict hatch dates.		
Biological control options	• A predatory mite, *Anystis wallacei*, was introduced to Australia for the biological control of RLEM. This predator has limited distribution and poor survival under continuous cropping systems and heavy grazing of pastures. • Other predatory mites (e.g. snout mites) are known to attack RLEM and have been shown to be effective in pasture systems. • Strategic manipulation of shelterbelts can provide a suitable habitat for RLEM natural enemies, which can then move into adjacent paddocks. • Populations of natural enemy species might be preserved through the use of 'softer' chemicals. The beneficials toxicity table developed by Cesar Australia helps growers make informed choices about the insecticides they use.	Michael *et al.* 1991; Ridsdill-Smith 1997; Ridsdill-Smith *et al.* 2008; Tsitsilas *et al.* 2011.	• Lack of practical knowledge around biological control of RLEM • Confusion around species status of RLEM (recent molecular data point to multiple species in South Africa that appear morphologically identical), which hinders attempts to identify natural enemies in South Africa. • Little research into how RLEM are kept in-check by natural enemies in South Africa. • Lack of robust evidence of the effect of chemicals on beneficials in field realistic conditions. • Efficacy of beneficials - particularly snout mites - in controlling RLEM in the absence of chemical spraying.

Table 2. Products with label claims for redlegged earth mite control in Australia

IRAC MoA group	Insecticide category	Example trade names	Active ingredient	Registered timing	Registered field crops and pastures
Group 1B	Organophosphates	Chlorpyrifos, Strike Out, Lorsban 500EC	chlorpyrifos	Spray; Pre and post-emergent	**Cereals,** Pastures, Forage crops. **Field Peas**, Broad beans, **Chickpeas, Lupins**, Lucerne, Clover Seed Crops, **Canola, Linseed**, **safflower**[1]. Silverbeet and Cole crops[2].
Group 1B	Organophosphates	Dimethoate, Danadim	dimethoate	Spray; Post emergent	**Cereals,** Pasture, Pasture Seed and Forage Crops, Lucerne, **Pulses, Canola, Linseed**, Mustard, Poppy, **Peanut, Sunflower**, Cotton. Tobacco[3]. Various horticultural crops.
Group 1B	Organophosphates	Fyfanon EW	malathion	Spray; Bare earth and post emergent	Vegetables.
Group 1B	Organophosphates	Le-Mat, Mite Master	omethoate	Spray; Pre and post-emergent	Pasture, **Cereals, Canola, Pulses.** Poppy[4].
Group 1B	Organophosphates	Thimet, Umet	phorate	Granular	Tomatoes.
Group 1B	Organophosphates	Imidan	phosmet	Spray; Pre and post-emergent	**Cereals,** Lucerne Pasture Seed Crops, Pasture.
Group 2B	Phenylpyrazoles	Cosmos, Legion	fipronil	Seed treatment	**Canola**[5].
Group 3A	Pyrethroids	Dominex Duo, Astound, Alpha-Scud	alpha-cypermethrin	Spray; Pre and post emergent	**Canola, Chickpea, Cereals, Faba beans, Field peas, Lupins,** Pastures.

Group 3A	Pyrethroids	Titan Cypermethrin, Cypershield	cypermethrin	Spray; Post emergent	**Canola.**
Group 3A	Pyrethroids	Talstar, Venom	bifenthrin	Spray; Pre and post emergent	**Canola, Faba beans**, Subterranean Clover, Clover, **Barley, Field peas, Lupins**, Lucerne, **Wheat.**
Group 3A	Pyrethroids	Trojan	gamma-cyhalothrin	Spray; Post-emergent	**Canola, Barley, Wheat, Field peas**, Lucerne, **Lupins**, Pasture, **Chickpea, Faba beans, Lentils, Vetch**.
Group 3A	Pyrethroids	Karate Zeon, Flipper	lambda-cyhalothrin	Spray; Post-emergent	**Barley, Wheat, Canola, Chickpea, Faba beans**, **Lentils**, **Vetch**, **Field peas,** Lucerne, **Lupins,** Pasture.
Group 3A	Pyrethroids	Sumi-alpha Flex	esfenvalerate	Spray; Pre and post emergent	Broad beans, **Faba beans, Canola, Chickpeas, Field peas, Lentils, Linseed,** Mustard, Lucerne, **Lupins,** Pasture, **Safflower, Wheat, Barley, Oats, Triticale.**
Group 4A	Neonicotinoids	Gaucho, Emerge, Senator	imidacloprid	Seed treatment	**Canola**, Forage and Seed Pasture, Clovers, Medics, Lucerne, **Lupins,** Forage Brassicas.
Group 4A	Neonicotinoids	Poncho Plus	imidacloprid & clothianidin	Seed treatment	**Canola**, Forage brassica, Pasture.
Group 1B/3A	Organophosphates / Pyrethroids	Pyrinex Super	chlorpyrifos & bifenthrin	Spray; Bare earth and post emergent in crop	**Canola**, Clover, **Barley,** Lucerne, **Wheat, Field peas, Lupins.**

Group 4A/3A	Neonicotinoids / Pyrethroids	Cruiser Opti	thiamethoxam & lambda-cyhalothrin	Seed treatment	**Canola, Cereals.**
Group 12A	Diafenthiuron	Pegasus, Receptor	diafenthiuron	Spray; Post emergent	**Canola.** **Winter cereals and pulse crops**[6].
Group 30	Meta-diamides, isoxazolines	Equento	isocycloseram	Seed treatment	**Canola.**

Source: APVMA-Public Chemical Registration Information System Search (PubCRIS), Australian Pesticides & Veterinary Medicines Authority; accessed October 2024.
Note: crops in **bold** are GRDC levy crops.
[1] Registered in NSW, ACT, WA only.
[2] Registered in NSW and ACT only.
[3] Registered in NSW and WA only.
[4] Registered in Tasmania only
[5] Not registered in Tasmania.
[6] Not registered; Permit number PER95087; SA and WA only (expires 30 September 2025).

Industry chemical use and secondary chemical exposure:

Cesar Australia led an extensive RLEM benchmarking between 2021 – 2022 involving broadacre growers and advisors (agronomists and consultants) across New South Wales, Victoria, Tasmania, South Australia and Western Australia. This information, along with data from Umina *et al.* (2019) and hundreds of spray records from growers across these states, was used to build a picture of the current approach to managing RLEM across southern Australia. Growers and advisors generally regard RLEM as a major and common pest, typically occurring yearly, or in some locations every 2-3 years depending on region and crop rotations. Canola was identified as being most vulnerable to RLEM attack, followed by establishing pastures and vetch crops. RLEM are less of a concern in cereal crops or other pulses. Most continuous pastures receive relatively few insecticide applications. The vast majority of canola crops are sown with seed treated with a neonicotinoid or neonicotinoid/pyrethroid insecticide. In many instances, growers are not offered an alternative by seed suppliers - depending on the agronomist and/or seed company used. Insecticide seed dressings are becoming more widely used in wheat, oats and barley, as well as on pastures.

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. In relation to RLEM evolving resistance to various chemical actives, most growers who responded were unsure whether RLEM had evolved resistance to OPs or SPs. OP and SP applications are either specifically targeted to RLEM or applied to combat several potential pests at seedling establishment. SP applications at the mature crop growth stages typically target Lepidopterans (caterpillars) and aphids. Lucerne flea is often a co-target in pastures and pulse crops, resulting in combined (tank mix) or repeat applications and more prominent use of OPs that target both mites and lucerne fleas.

The volume of insecticide and active ingredients used to control RLEM varies between south-eastern (SE) Australia and Western Australia (WA); an observation consistent with the extent and evidence of SP resistance across WA, compared with SE Australia. Based on spray records and limited phone surveys, it appears foliar insecticides are sprayed (on average) in about 80% (WA) and 20% (SE Australia) of canola paddocks annually. Within SE Australia, reported chemical usage against RLEM is typically within label recommendations and generally applied on a field-by-field basis, meaning frequent or "blanket" sprays are uncommon. In WA, usage of SPs and OPs either individually or as mixtures is commonplace. Application rates in WA are often targeted to multiple seedling pests and consequently are sometimes applied above label recommendations for RLEM.

Table 3. Current status of insecticide resistance in the redlegged earth mite within Australia

Attribute	What is known?	References	Knowledge gaps
Resistance status	• Confirmed widespread and very high levels of resistance to SPs, and widespread, moderate levels of resistance to OPs across the Western Australian grainbelt. • Confirmed and very high levels of resistance to SPs, and moderate levels of resistance to OPs in several areas of SA, including Kangaroo Island, the Fleurieu Peninsula, the south east and the mid-north regions. • Several OPS resistant RLEM populations have been detected in parts of Victoria; in the north central region and more recently in the Wimmera. • SP resistance has not been detected in Victoria. • Some RLEM populations in WA and SA have been found to exhibit dual resistance to both SPs and OPs • No known resistance to neonicotinoids in Australia.	Umina 2007; Umina *et al.* 2012; Maino *et al.* 2018; Arthur *et al.* 2021; Umina *et al.* 2023.	• Thorough understanding of resistance risk to neonicotinoids.
Mechanism of resistance & cross-resistance	• SPs: para-sodium channel (mutation at *kdr* locus which causes target site modification) is the main resistance mechanism. • OP resistance is probably metabolic and polygenic. Mutations in the acetylcholinesterase and the potential role of copy number variation in the acetylcholinesterase gene have been identified. • Dual resistance to SPs and OPs present is some populations in WA & SA.	Edwards *et al.* 2018; Cheng *et al.* 2019; Thia *et al.* 2023.	• The mechanisms underlying OP resistance. • How widely spread different target-site mutations are – limited samples and lack of screening for the novel mutations for SPs means these may have gone undetected.
Known fitness costs	• Field observations and laboratory trials suggest modest fitness costs with SP resistance but there are potentially large fitness costs associated with OP resistance.	Cheng *et al.* 2021; Umina *et al.* 2022.	• Assessment of fitness costs for OP resistance.

Genetic basis for resistance	• SPs: *kdr* resistance is incompletely recessive.	Edwards *et al.* 2018; Cheng *et al.* 2019; Maino *et al.* 2021.	• Genetic basis for resistance for OP resistance. • Extent of dominance across time with decay of pesticide remains to be established.
Origin of resistance	• Can involve local development from rare alleles or through mutation followed by gene flow. • Long distance movement of resistance alleles has contributed to the spread of resistance. • Research highlights multiple independent evolutionary events leading to resistance in RLEM.	Edwards *et al.* 2018; Yang *et al.* 2020.	• Potential for local development of resistance if exposed to adequate selection pressures.
Resistance management	• Weed control in fencelines will reduce resistance evolution compared with spraying fencelines with a pesticide. • Spraying strips with 10 m unsprayed can reduce resistance evolution due to recessive SP resistance. • Proximity to known resistance location increases risk of resistance, thus farm biosecurity practices will likely reduce resistance spread. • Resistance ratios in RLEM populations are much higher in SPs (~ 200,000 times) than OPs (~4-414 times); OPs may still provide some level of control of RLEM even when resistance has been detected. • Resistances to OPs is moderate but varies depending on the active ingredient. Results from lab and field trials indicate that omethoate tends to outperform chlorpyrifos in terms of control. • New in-field test developed for growers to rapidly detect SP resistance to be available in 2024.	Maino *et al.* 2019; Maino *et al.* 2021; Arthur *et al.* 2021; Umina *et al.* 2023; P. Umina (unpubl).	• The efficacy of strip spraying in delaying resistance should be verified at farm scale trials, including in pastures.
Impact of RLEM control on natural enemies	• Chlorpyrifos and omethoate have 'Very High' toxicity to several natural enemies of RLEM, including predatory mites,	Knapp *et al.* 2023.	• Bioassays still need to be conducted on some predators of RLEM, including

	while dimethoate ranges from ‘Low’ to ‘Very High’ toxicity, depending on the predatory species. • SPs are highly toxic to several predatory mite species. • Diafenthiuron has a medium to high toxicity to several predatory mites of RLEM, including snout mites.		several spider species and snout mites.

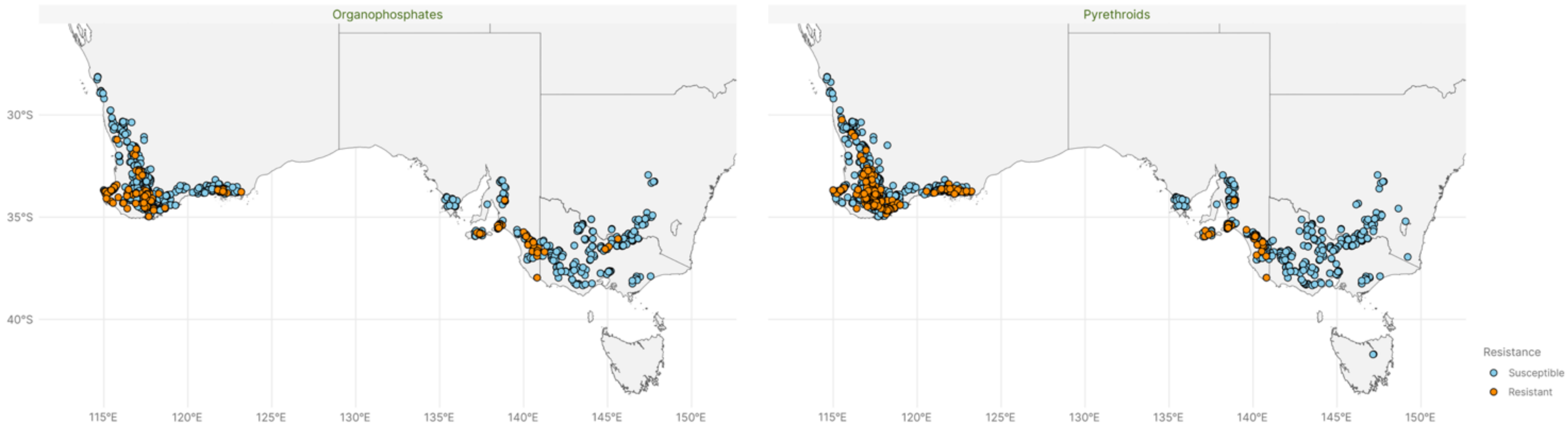
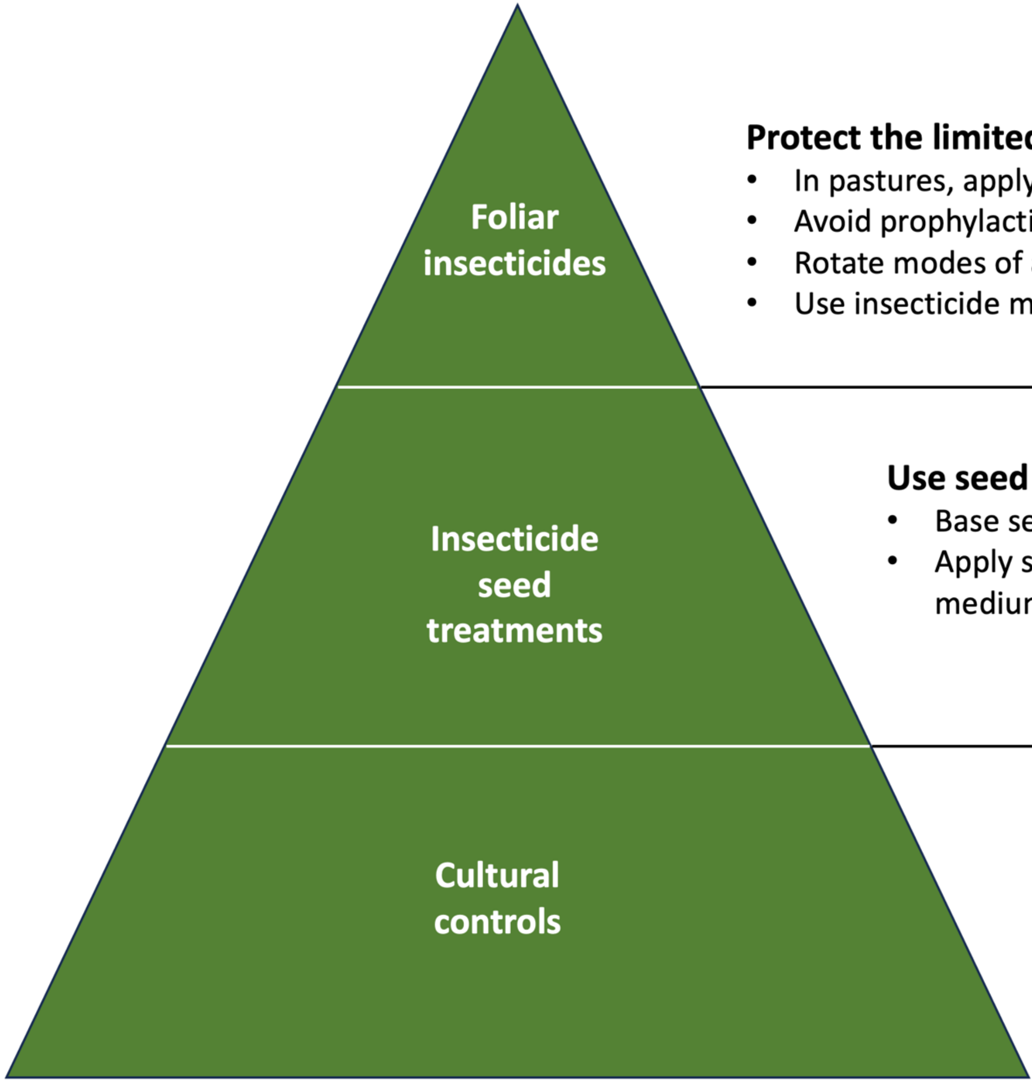


Figure 1. The distribution of RLEM populations screened for organophosphate (left panel) and pyrethroid (right panel) resistance across Australia as of 2024. Orange circles represent populations with resistance, and blue circles indicate populations that are susceptible to pesticides (Cesar Australia, 2024).



Protect the limited insecticides available

- In pastures, apply Timerite® in the previous spring if RLEM are abundant
- Avoid prophylactic pre-emergence/bare-earth sprays in autumn
- Rotate modes of action (MOA) when controlling RLEM and other pests
- Use insecticide mixtures strategically and only in the absence of resistance

Use seed treatments based on risk

- Base seed treatment decisions on RLEM risk
- Apply seed treatments when RLEM pressure is predicted to be medium or high during seedling establishment

Start with a solid foundation

- Graze pastures in spring to below 2t/ha dry matter
- Keep paddocks and fencelines weed-free
- Use higher seeding rates for canola if RLEM pressure is predicted to be high
- Sow mite-tolerant crops

Figure 2. Infographic of key management recommendations for the RLEM.

Table 4A. Chemical windowing strategy for situations where RLEM have no resistance

Crop windows	Insecticide recommendations	Rationale	Other considerations	Handy tips
Previous spring	A spring TimeRite® application of omethoate (1B)	Omethoate has a long residual and will better compensate than other OPs for annual variations in the timing of RLEM diapause egg production.	In pastures, use stock grazing to reduce feed-on-offer prior to TimeRite® date as an alternative to applying a chemical.	Ensure correct ID of mites; TimeRite® is not effective against other pest mites.
Pre-emergence & sowing	A single seed treatment application of one of the following: - Imidacloprid (4A) - Clothianidin + imidacloprid (4A + 4A) - Lambda cyhalothrin + thiamethoxam (3A + 4A) - Thiamethoxam + isocycloseram (4A + 30) - Fipronil (2B) Avoid pre-emergence/bare earth sprays wherever possible, especially for early sowing opportunities. If unavoidable, use an SP if omethoate used at TimeRite® date.	All seed treatments currently registered against RLEM remain effective. Limiting spray applications at pre-emergence will provide greater flexibility in chemical choice at later crop stages. Applying an OP at TimeRite® and again at pre-emergence should be avoided, as these will be consecutive mite generations and will increase selection for OP resistance.	Do not used seed treatments if mite pressure is predicted to be Low.	Refer to the severity risk assessment form to determine RLEM risk and appropriate management actions.
Early post-emergence (Oilseeds – up to 6-leaf) (Cereals – up to tillering)	In canola, a single application of: Diafenthiuron (12A)[1]	There is no resistance to diafenthiuron in RLEM. Using this chemical over SPs and OPs will decrease the likelihood of resistance emerging.	Monitoring is required to determine if chemical intervention is needed. Refer to economic thresholds	When monitoring for RLEM, use visual inspections, preferably when the conditions are dry. Monitor at least 10

(Pulses – up to 4-leaf) (Annual pastures - up to 5 weeks post emergence)	In pastures and other crops, a single application of: an OP (1B) or an SP (3A) If a chemical from either chemical group has been used at pre-emergence or as a seed treatment, apply a chemical from the alternative group. If neither an OP (1B) or SP (3A) has been applied at pre-emergence or as a seed treatment, apply a mixture of OP & SP (1B + 3A).	Avoiding the same chemical group across two consecutive mite generations decreases the likelihood of resistance emerging. Applying a co-formulation or mixture of two chemical groups can be an effective resistance management strategy if there is no resistance already present and neither chemical group is used in adjacent crop windows.	Where co-formulations or mixtures are used, they should be considered as two independent applications (one for each chemical group), and therefore this needs to be reconciled by avoiding applications of the same chemical groups in adjacent crop windows. If applying a mixture or co-formulation, ensure a full dose rate of each chemical is applied (i.e. sufficient to control RLEM if applied as a stand-alone product).	sampling points across the paddock, ensuring you move away from fence-lines, to get a representative sample. Refer to the RLEM hatch timing tool to focus monitoring efforts.
Later crop stages	Avoid the use of SPs (3A) and OPs (1B) when targeting other pests whenever possible.	RLEM do not typically warrant chemical control at later crop stages.	If OPs and SPs are used for other pests, doing so will select for resistance in RLEM	

[1] Diafenthiuron also available for use in winter cereals and pulses in SA and WA only (Permit number PER95087; expires 30 September 2025).

Table 4B. Chemical windowing strategy for situations where RLEM have resistance to OPs only

Crop windows	Insecticide recommendations	Rationale	Other considerations	Handy tips
Previous spring	A spring TimeRite® application of omethoate (1B)[1]	Omethoate has a long residual and will better compensate than other OPs for annual variations in the timing of RLEM diapause egg production.	In RLEM, resistance is not always ubiquitous across all OPs, thus omethoate (1B) may still provide sufficient control of mites.[1] Growers should test the response of RLEM in a small area first. In pastures, use stock grazing to reduce feed-on-offer prior to TimeRite® date as an alternative to applying a chemical.	Ensure correct ID of mites; TimeRite® is not effective against other pest mites.
Pre-emergence & sowing	A single seed treatment application of one of the following: - Imidacloprid (4A) - Clothianidin + imidacloprid (4A + 4A) - Lambda cyhalothrin + thiamethoxam (3A + 4A) - Thiamethoxam + isocycloseram (4A + 30) - Fipronil (2B) Avoid pre-emergence/bare earth sprays wherever possible, especially for early sowing opportunities. If unavoidable, use an SP. Do not use a mixture or co-formulation containing an	All seed treatments currently registered against RLEM remain effective against resistant mites. Use of OPs for RLEM control not recommended due to resistance. Minimising the use of OPs will decrease the risk of this chemical group becoming completely ineffective against RLEM. Limiting spray applications at pre-emergence will provide greater flexibility in chemical choice at later crop stages.	Do not used seed treatments if mite pressure is predicted to be Low.	Refer to the severity risk assessment form to determine RLEM risk and appropriate management actions

	OP.			
Early post-emergence (Oilseeds – up to 6-leaf) (Cereals – up to tillering) (Pulses – up to 4-leaf) (Annual pastures - up to 5 weeks post emergence)	In canola, a single application of: Diafenthiuron (12A)[2] In pastures and other crops, a single application of an SP, if not used at pre-emergence. Do not use a mixture or co-formulation containing an OP.	Use of OPs for RLEM control not recommended due to resistance. Minimising the use of OPs will decrease the risk of this chemical group becoming completely ineffective against RLEM.	Monitoring is required to determine if chemical intervention is needed. Refer to economic thresholds In RLEM, resistance is not always ubiquitous across all OPs, thus an OP may still provide sufficient control of mites.[1] Growers should test the response of RLEM in a small area first.	When monitoring for RLEM, use visual inspections, preferably when the conditions are dry. Monitor at least 10 sampling points across the paddock, ensuring you move away from fence-lines, to get a representative sample Refer to the RLEM hatch timing tool to focus monitoring efforts
Later crop stages	Avoid the use of SPs and OPs when targeting other pests whenever possible. Only use SPs if not already used at post-emergence.	RLEM do not typically warrant chemical control at later crop stages. Use of SPs across consecutive windows will increase selection for resistance to this chemical group.	If OPs and SPs are used for other pests, doing so will select for resistance in RLEM	

[1] Some RLEM populations resistant to omethoate & dimethoate have not demonstrated cross-resistance to chlorpyrifos, and vice versa. Thus OPs may offer effective control in the short-term and rotating between OPs may be an option.
[2] Diafenthiuron also available for use in winter cereals and pulses in SA and WA only (Permit number PER95087; expires 30 September 2025).

Table 4C. Chemical windowing strategy for situations where RLEM have resistance to SPs only

Crop windows	Insecticide recommendations	Rationale	Other considerations	Handy tips
Previous spring	A spring TimeRite® application of omethoate (1B)	Omethoate has a long residual and will better compensate than other OPs for annual variations in the timing of RLEM diapause egg production.	In pastures, use stock grazing to reduce feed-on-offer prior to TimeRite® date as an alternative to applying a chemical.	Ensure correct ID of mites; TimeRite® is not effective against other pest mites.
Pre-emergence & sowing	A single seed treatment application one of the following: - Imidacloprid (4A) - Clothianidin + imidacloprid (4A + 4A) - Thiamethoxam + isocycloseram (4A + 30) - Fipronil (2B) Avoid pre-emergence/bare earth sprays wherever possible, especially for early sowing opportunities. If unavoidable, use an OP but not omethoate if TimeRite® was used last spring. Do not use a mixture or co-formulation containing an SP.	All seed treatments currently registered against RLEM remain effective against resistant mites. Limiting spray applications at pre-emergence will provide greater flexibility in chemical choice at later crop stages. Use of SPs for RLEM control not recommended in any crop window if resistance to this group is present; applications of SPs will not provide adequate control of RLEM and will rapidly select for further resistance.	Do not used seed treatments if mite pressure is predicted to be Low. Applying an OP at TimeRite® and again at pre-emergence should be avoided, as these will be consecutive mite generations and will increase selection for OP resistance. If unavoidable, use a different OP to the previous application given resistance in RLEM is not always ubiquitous across all OPs	Refer to the severity risk assessment form to determine RLEM risk and appropriate management actions
Early post-emergence (Oilseeds – up to 6-leaf) (Cereals – up to tillering)	In canola, a single application of: Diafenthiuron (12A)[1] In pastures and other crops, a	Use of SPs for RLEM control not recommended in any crop window if resistance to this group is present; applications of SPs will not provide	Monitoring is required to determine if chemical intervention is needed. Refer to economic thresholds	When monitoring for RLEM, use visual inspections, preferably when the conditions are dry. Monitor at least 10

(Pulses – up to 4-leaf) (Annual pastures - up to 5 weeks post emergence)	single application of: an OP, if not used at pre-emergence. Do not use a mixture or co-formulation containing an SP.	adequate control of RLEM and will rapidly select for further resistance.		sampling points across the paddock, ensuring you move away from fence-lines, to get a representative sample Refer to the RLEM hatch timing tool to focus monitoring efforts
Later crop stages	Avoid the use of SPs and OPs when targeting other pests whenever possible. Only use OPs if not already used at post-emergence.	RLEM do not typically warrant chemical control at later crop stages. Use of OPs across consecutive windows will increase selection for resistance to this chemical group.	If OPs and SPs are used for other pests, doing so will select for resistance in RLEM	

[1] Diafenthiuron also available for use in winter cereals and pulses in SA and WA only (Permit number PER95087; expires 30 September 2025).

Table 4D. Chemical windowing strategy for situations where RLEM have resistance to SPs and OPs

Crop windows	Insecticide recommendations	Rationale	Other considerations	Handy tips
Previous spring	A spring TimeRite® application of omethoate (1B)[1]	Omethoate has a long residual and will better compensate than other OPs for annual variations in the timing of RLEM diapause egg production.	In RLEM, resistance is not always ubiquitous across all OPs, thus omethoate (1B) may still provide sufficient control of mites.[1] Growers should test the response of RLEM in a small area first. In pastures, use stock grazing to reduce feed-on-offer prior to TimeRite® date as an alternative to applying a chemical.	Ensure correct ID of mites; TimeRite® is not effective against other pest mites.
Pre-emergence & sowing	A single seed treatment application of one of the following: - Imidacloprid (4A) - Clothianidin + imidacloprid (4A + 4A) - Thiamethoxam + isocycloseram (4A + 30) - Fipronil (2B)	All seed treatments currently registered against RLEM remain effective against resistant mites. Use of SPs for RLEM control not recommended in any crop window if resistance to this group is present; applications of SPs will not provide adequate control of RLEM and will rapidly select for further resistance.	Do not used seed treatments if mite pressure is predicted to be Low. Do not apply pre-emergence/bare earth sprays as this will provide greater flexibility in chemical choice at later crop stages.	Refer to the severity risk assessment form to determine RLEM risk and appropriate management actions
Early post-emergence (Oilseeds – up to 6-leaf) (Cereals – up to tillering)	In canola, a single application of: Diafenthiuron (12A)[2] In pastures and other crops, a	Use of SPs for RLEM control not recommended in any crop window if resistance to this group is present; applications of SPs will not provide	Monitoring is required to determine if chemical intervention is needed. Refer to economic thresholds.	When monitoring for RLEM, use visual inspections, preferably when the conditions are dry. Monitor at least 10

(Pulses – up to 4-leaf) (Annual pastures - up to 5 weeks post emergence)	single application of: an OP, if not used at pre-emergence. Do not use a mixture or co-formulation containing an SP.	adequate control of RLEM and will rapidly select for further resistance.	In RLEM, resistance is not always ubiquitous across all OPs, thus an OP may still provide sufficient control of mites.[1] Growers should test the response of RLEM in a small area first.	sampling points across the paddock, ensuring you move away from fence-lines, to get a representative sample Refer to the RLEM hatch timing tool to focus monitoring efforts
Later crop stages	Avoid the use of SPs and OPs when targeting other pests whenever possible. Only use OPs if not already used at post-emergence.	RLEM do not typically warrant chemical control at later crop stages. Use of OPs across consecutive windows will increase selection for resistance to this chemical group.	If OPs and SPs are used for other pests, doing so will select for resistance in RLEM	

[1] Some RLEM populations resistant to omethoate & dimethoate have not demonstrated cross-resistance to chlorpyrifos, and vice versa. Thus OPs may offer effective control in the short-term and rotating between OPs may be an option.

[2] Diafenthiuron also available for use in winter cereals and pulses in SA and WA only (Permit number PER95087; expires 30 September 2025).

Table 5. Chemical considerations for RLEM.

Insecticide	IRAC MoA group	Considerations
Organophosphates (OPs)	1B	OP resistance is present in WA, SA and Vic. The levels of resistance in RLEM are low-moderate and there is not always cross-resistance across OP active ingredients. Thus, OPs may offer effective control in the short-term; although undesirable, rotating between OPs is an option. Growers should test the response of RLEM in a small area first. Be aware that water quality and pH can affect the efficacy of some OPs through alkaline hydrolysis.
Fipronil (e.g. Cosmos®)	2B	Registered as seed treatment (canola only). Only provides adequate protection from low RLEM pressure.
Synthetic pyrethroids (SPs)	3A	SP resistance is common in WA and parts of SA. The levels of SP resistance are always high, and there is cross-resistance across this entire chemical group. Applications of SPs on resistant mites are ineffective.
Neonicotinoids (e.g. Gaucho®)	4A	Registered as seed treatments. No resistance in Australian RLEM.
Diafenthiuron (e.g. Receptor®)	12A	Registered as a foliar spray in canola only. Also available for use in winter cereals and pulses in SA and WA only (Permit number PER95087; expires 30 September 2025). Thorough coverage is needed and best applied after the 2-leaf stage. No resistance in Australian RLEM.
Isocycloseram (Equento®)	30	Registered as seed treatment (canola only). No resistance in Australian RLEM.

References

APVMA – Australian Pesticides and Veterinary Medicines Authority, *Public Chemical Registration Information System Search* (https://portal.apvma.gov.au/pubcris)

Arthur A, Hoffmann A and Umina P. 2013. Impact of *Halotydeus destructor* on crop seedlings at different plant developmental stages and levels of moisture stress. *Environmental Entomology* 45: 998-1012.

Arthur AL, Hoffmann AA and Umina PA. 2015. Challenges in devising economic spray thresholds for a major pest of Australian canola, the redlegged earth mite (*Halotydeus destructor*). *Pest Management Science* 71: 1462-1470.

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

Cheng X, Hoffmann A, Maino J and Umina P. 2018a. A cryptic diapause strategy in *Halotydeus destructor* (Tucker) (Trombidiformes: Penthaleidae) induced by multiple cues. *Pest Management Science* 74: 2618-2625.

Cheng X, Umina P and Hoffmann A. 2018b. Influence of previous host plants on the reproductive success of a polyphagous mite pest, *Halotydeus destructor. Journal of Economic Entomology* 111: 680-688.

Cheng X, Umina P, Lee R and Hoffmann A. 2019. Pyrethroid resistance in the pest mite, *Halotydeus destructor*: dominance patterns and a new method for resistance screening. *Pesticide Biochemistry and Physiology* 159: 9-16.

Cheng X, Hoffmann AA, Edwards OR and Umina PA. 2021. Fitness costs associated with pyrethroid resistance in *Halotydeus destructor* Tucker (Acari: Penthaleidae) elucidated through semi-field trials. *Journal of Economic Entomology* 114: 1270-1281.

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

Gaull KR and Ridsdill-Smith TJ. 1997. Host plant acceptance by the redlegged earth mite, *Halotydeus destructor* (Tucker) (Acarina: Penthaleidae). *Journal of Insect Behaviour* 10: 859-869.

Hill MP, Elith J, Macfadyen S, Umina PA and Hoffmann AA. 2012. Understanding niche shifts: using current and historical data to model the invasive redlegged earth mite, *Halotydeus destructor*. *Diversity and Distributions* 18: 191-203.

Hill MP, Chown SL and Hoffmann AA. 2013. A predicted niche shift corresponds with increased thermal resistance in an invasive mite, *Halotydeus destructor*. *Global Ecology and Biogeography* 22: 942–951.

Hill MP, Hoffmann AA, Umina PA, Cheng X and Miller AD. 2016. Genetic analysis along an invasion pathway reveals endemic cryptic taxa, but a single species with little population structure in the introduced range. *Diversity and Distributions* 22: 57-72.

Knapp R, McDougall R, Overton K, Hoffmann A, Ward S and Umina P. 2023. Impact of insecticides on beneficial insects in Australian grain crops. *Cesar Australia*. https://cesaraustralia.com/wp-content/uploads/2022/05/Cesar-Beneficials-Chemical-Toxicity-Table-v2.0.pdf

MacLennan KE, McDonald G and Ward SA. 1998. Soil microflora as hosts of redlegged earth mite (*Halotydeus destructor*). *Entomologia Experimentalis et Applicata* 86: 319–323.

Maino J, Binns M and Umina P. 2018. No longer a west-side story – pesticide resistance discovered in the eastern range of a major Australian crop pest, *Halotydeus destructor* (Acari: Penthaleidae). *Crop and Pasture Science* 69: 216-221.

Maino J, Renton M, Hoffmann A and Umina PA. 2019. Field margins provide a refuge for pest genes beneficial to resistance management. *Journal of Pest Science* 92: 1017-1026.

Maino J, Hoffmann A, Binns M, Cheng X, van Rooyen A and Umina P. 2021. Strip spraying delays pyrethroid resistance in the redlegged earth mite, *Halotydeus destructor*: a novel refuge strategy. *Pest Management Science* 77: 4572-4582.

Maino JL, Umina PA, Pavri C, Cheng X and Ridsdill-Smith J. 2024. Adapting pest management strategies to changing climates for the redlegged earth mite, *Halotydeus destructor*. *Scientific Reports* 14: 16939.

McDonald G, Moritz K, Merton E and Hoffmann AA. 1995. The biology and behaviour of redlegged earth mite and blue oat mite on crop plants. *Plant Protection Quarterly* 10: 52–55.

McDonald G, Umina PA, MacFadyen S, Mangano P and 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.

Michael PJ, Dutch ME and Pekin CJ. 1991. A review of the predators of redlegged earth mites, blue oat mite and lucerne flea. In: Risdsill-Smith TJ (ed.), Proceedings of a National Workshop on the redlegged earth mite, lucerne flea and blue oat mite. Department of Agriculture, South Perth, Australia, pp. 115-120.

Murray DAH, Clarke MB and Ronning DA. 2013. Estimating invertebrate pest losses in six major Australian grain crops. *Australian Journal of Entomology* 53: 227-241.

Risdsill-Smith TJ. 1997. Biology and control of *Halotydeus destructor* (Tucker) (Acarina: Penthaleidae): a review. *Experimental and Applied Acarology* 21: 195-224.

Ridsdill-Smith TJ and Annells AJ. 1997. Seasonal occurrence and abundance of redlegged earth mites *Halotydeus destructor* (Acari: Penthaleidae) in annual pastures of southwestern Australia. *Bulletin of Entomological Research* 87: 413–423.

Ridsdill-Smith TJ and Pavri CC. 2000. Feeding lifestyle of redlegged earth mite, *Halotydeus destructor* (Acari: Penthaleidae), in pastures and the role of broad-leafed weeds. *Experimental and Applied Acarology* 24: 397-414.

Ridsdill-Smith J, Pavri C, De Boer E and Kriticos D. 2005. Predictions of summer diapause in the redlegged earth mite, *Halotydeus destructor* (Acari : Penthaleidae), in Australia. *Journal of Insect Physiolog*y 51: 717-726.

Ridsdill-Smith TJ, Hoffmann AA, Mangano GP, Gower JM, Pavri CC and Umina PA. 2008. Strategies for control of the redlegged earth mite in Australia. *Australian Journal of Experimental Agriculture* 48: 1506–1513.

Ridsdill-Smith T, Smith H, Read J and Pavri C. 2013. Population ecology of *Halotydeus destructor* in pastures. *Integrated Control of Plant-Feeding Mites IOBC-WPRS Bulletin* 93: 91-101.

Robinson MT and Hoffmann AA. 2001. The pest status and distribution of three cryptic blue oat mite species (*Penthaleus* spp.) and the redlegged earth mite (*Halotydeus destructor*) in southeastern Australia. *Experimental and Applied Acarology* 25: 699-716.

Tsitsilas A, Hoffmann AA, Weeks AR and Umina PA. 2011. Impact of groundcover manipulations within windbreaks on mite pests and their natural enemies. *Australian Journal of Entomology* 50: 37-47.

Thia JA, Cheng X, Maino J, Umina PA and Hoffmann AA. 2022. Warmer temperatures reduce chemical tolerance in the redlegged earth mite (*Halotydeus destructor*), an invasive winter-active pest. *Pest Management Science* 78: 3071–3079.

Thia JA, Umina PA, Hoffmann A. 2023. Ace and ace-like genes of invasive redlegged earth mite: copy number variation, target-site mutations, and their associations with organophosphate insensitivity. *Pest Management Science* doi: 10.1002/ps.7619

Umina PA. 2007. Pyrethroid resistance discovered in a major agricultural pest in southern Australia: the redlegged earth mite (Acari: Penthaleidae). *Pest Management Science* 63: 1185-1190.

Umina PA and Hoffmann AA. 2003. Diapause and implications for control of *Penthaleus* species and *Halotydeus destructor* (Acari: Penthaleidae) in southeastern Australia. *Experimental and Applied Acarology* 31: 209-223.

Umina PA and Hoffmann AA. 2004. Plant host associations of *Penthaleus* species and *Halotydeus destructor* (Acari: Penthaleidae) and implications for integrated pest management. *Experimental and Applied Acarology* 33: 1-20.

Umina PA, Weeks AR, Roberts J, Jenkins S, Mangano P, Lord A and Micic S. 2012. The current status of pesticide resistance in Australian populations of the redlegged earth mite (*Halotydeus destructor*). *Pest Management Science* 68: 889-896.

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

Umina PA, Maino JL, Edwards E, Cheng X, Binns M, van Rooyen A, Vern Song S, Weeks A, Arthur AL, Reynolds OL, Hoffmann AA. 2022. Fitness costs of pyrethroid resistance in the polyphagous pest mite, *Halotydeus destructor*, under field conditions. *Journal of Pest Science* doi: 10.1007/s10340-023-01605-9

Umina PA, McGrane L, Thia J, Chirgwin E and Hoffmann AA. 2023. From laboratory to field: laboratory-measured pesticide resistance reflects outcomes of field-based control in the redlegged earth mite, *Halotydeus destructor*. *Experimental and Applied Acarology* doi: 10.1007/s10493-023-00787-2

Wallace, MMH. 1970. Diapause in the aestivating egg of *Halotydeus destructor* (Acari: Eupodidae). *Australian Journal of Zoology* 18: 295-313.

Wallace MMH and Mahon JA. 1971. The distribution of *Halotydeus destructor* and *Penthaleus major* (Acari: Eupodidae) in Australia in relation to climate and land use. *Australian Journal of Zoology* 19: 65-76.

Weeks AR, Fripp Y and Hoffmann AA. 1995. Genetic structure of *Halotydeus destructor* and *Penthaleus major* populations in Victoria (Acari: Penthaleidae) *Experimental & Applied Acarology* 19: 633-646.

Weeks AR and Hoffmann AA. 2000. Dispersal patterns of pest earth mites (Acari: Penthaleidae) in pastures and crops. *Journal of Economic Entomology* 93: 1415-1423.

Yang Q, Umina PA, Rasic G, Bell N, Fang J, Lord A, Hoffmann AA. 2020. Origin of resistance to pyrethroids in the redlegged earth mite (*Halotydeus destructor*) in Australia: repeated local evolution and migration. *Pest Management Science* 76: 509-519.