Science behind the resistance management strategy for the redlegged earth mite *(Halotydeus destructor)* in Australian grains and pastures

Developed by the National Insecticide Resistance Management (NIRM) working group of the Grains Pest Advisory Committee (GPAC)

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

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

This document details the scientific and industry information used in the development of the Resistance Management Strategy for the redlegged earth mite in Australian grains and pastures. To download the GPA Resistance Management Strategy visit: http://ipmguidelinesforgrains.com.au/ipm-information/resistance-management-strategies.

GRDC Project Code: UM00048

Authors:
Contributing authors: Dr Paul Umina (**cesar**) (principal), Professor Ary Hoffmann (The University of Melbourne), Dr Garry McDonald (The University of Melbourne), Dr Owain Edwards (CSIRO), Mr Peter Mangano (formerly DAFWA), Dr Melina Miles (Queensland DAF), Mr Greg Baker (SARDI), Mr Geoff Cornwell (DuPont Crop Protection), Professor Stephen Powles (UWA) and Nancy Schellhorn (CSIRO).

Special thanks to Warwick Nightingale (Delta Agribusiness), Annabel Clouston (**cesar**), James Maino (The University of Melbourne), Sally Ceeney (Ceeney Agricultural Consultants), Ken McKee (Syngenta Crop Protection), the CropLife Australia Insect Resistance Management Review Group and the Grains Research & Development Corporation

ISBN: 978-1-921779-98-5

Published September 2016. Copyright © Grains Research and Development Corporation 2016

Enquiries and additional copies: Grains Research and Development Corporation Ground Cover Direct
W: www.grdc.com.au/bookshop **E:** ground-cover-direct@canprint.com.au **T:** + 61 02 6166 4500 **F:** +61 02 6166 4599

Design and production: coretext.com.au

1. 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 grow in Australia, placing strong selection pressure for the development of resistance. High levels of resistance to synthetic pyrethroids (SPs), including bifenthrin and alpha-cypermethrin, are becoming more common across the Western Australian grainbelt. Localised resistance to organophosphates (OPs), including omethoate and chlorpyrifos, has recently been discovered on multiple WA properties. At present, there is no confirmed resistance to any insecticide outside of WA. Growers should understand how to minimise 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.

This document forms the scientific basis upon which RLEM resistance management strategies were developed. Due to local differences in resistance levels, there is a need to implement resistance management that is locally relevant.

TABLE 1 Background information on the redlegged earth mite (RLEM), *Halotydeus destructor.*

Attribute	What is known about RLEM?	References
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.* 2013; Murray *et al.* 2013.
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 (including number of generations)	• RLEM typically completes 3 generations per season (occasionally a 4th 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. • Autumn rainfall, accompanied by cool temperatures, is required to break summer dormancy and commence egg hatch. Egg hatch temperature requirements vary across Australian RLEM populations.	Wallace 1970; Ridsdill-Smith 1997; Umina & Hoffmann 2003; Ridsdill-Smith *et al.* 2005; McDonald *et al.* 2015.
Crop hosts	• Very broad host range. Includes pasture legumes, grasses, grain crops, vegetables and cut flowers. • In grains they are known to attack canola, wheat, barley, oats, lupins, sunflowers, faba beans, field peas, poppies, lucerne and vetch. • Compensation for damage can occur in crops including canola, highlighting importance of thresholds.	Ridsdill-Smith 1997; Robinson & Hoffmann 2001; Umina & Hoffmann 2004; Ridsdill-Smith *et al.* 2013; Arthur *et al.* 2015.
Non-crop hosts	• Many weeds, especially broad-leaved weeds such as capeweed, plantain and bristly ox-tongue.	Ridsdill-Smith 1997; Umina & Hoffmann 2004; Ridsdill-Smith *et al.* 2013.
Distribution	• Likely origin around 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 Queensland; distribution limits relate to aridity and seasonality. • Geographic range shifts evident in past 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.

TABLE 1 CONTINUED ON PAGE 4

TABLE 1 Background information on the redlegged earth mite (RLEM)

Attribute	What is known about RLEM?	References
Dispersal/ movement	• In winter grain crops and pastures, RLEM walk to disperse. 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 no strong differentiation between eastern and western Australian populations and within these areas, suggesting ongoing gene flow across regions of Australia and/or very large founding populations.	Ridsdill-Smith 1997; Weeks *et al*. 2000; Hill *et al*. 2015.
Feeding behaviour	• Sucking pest: mites make a hole approximately 3 µm in diameter and cell contents are sucked out using a pharyngeal pump. • RLEM tend to feed in aggregations of up to 40 individuals; they are attracted to plant volatiles released as a result of mite feeding. • Mites spend the majority of their time on or near the soil surface, only moving onto plants to feed. • In grains crops, RLEM cause most damage during 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; Arthur *et al*. 2013; Ridsdill-Smith *et al*. 2013.
Chemical controls	• Chemicals remain key in grains as well as other industries. • As of March 2015, there were approximately 200 insecticide products for mites registered in Australia. These are primarily from 3 chemical groups: organophosphates (e.g. dimethoate), synthetic pyrethroids (e.g. alpha-cypermethrin) and neonicotinoids (e.g. imidacloprid).	Umina 2007; APVMA.
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.	Michael *et al*. 1991; Ridsdill-Smith 1997; Tsitsilas *et al*. 2011.

2. INSECTICIDE REGISTRATIONS AND USAGE IN AUSTRALIA

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

IRAC MoA group	Insecticide category	Active ingredient	Example trade names	Registered timing	Registered field crops and pastures
Group 1B	Organophosphates	Chlorpyrifos	Chlorpyrifos, Strike Out	Spray; pre and post-emergent	Cereals, pasture, canola, field peas, Chickpea, lupins, lucerne, pasture, clover/medic, wheat, oats, barley, triticale
Group 1B	Organophosphates	Dimethoate	Dimethoate, Danadim	Spray; post-emergent	Cereals, pasture, lucerne, clover/ medic, field peas, pulses, canola, peanut, sunflower
Group 1B	Organophosphates	Methidathion	Suprathion	Spray; bare earth and post-emergent	Cereals, pasture, canola, lucerne, lupins
Group 1B	Organophosphates	Omethoate	Le Mat, All-Mitey	Spray; pre and post-emergent	Pasture, cereals, canola, pulses
Group 1B	Organophosphates	Phosmet	Imidan	Spray; pre and post-emergent	Cereals, lucerne, pasture
Group 2B	Phenylpyrazoles	Fipronil	Cosmos, Legion	Seed treatment	Canola[1]
Group 3A	Pyrethroids	Alpha-cypermethrin	Fastac, Dominex Duo, Astound	Spray; pre and post-emergent	Canola, chickpea, cereals, faba beans, field peas, lupins, pasture
Group 3A	Pyrethroids	Cypermethrin	Scud Elite	Spray; pre and post-emergent	canola, wheat, barley, triticale,
Group 3A	Pyrethroids	Bifenthrin	Talstar, Venom	Spray; pre and post-emergent	Faba beans, clover/medic, barley, canola, field peas, lupins, lucerne, wheat
Group 3A	Pyrethroids	Gamma-cyhalothrin	Trojan	Spray; post-emergent	Canola, barley, wheat, field peas, lucerne, lupins, pasture, chickpea, Faba beans
Group 3A	Pyrethroids	Lambda-cyhalothrin	Karate Zeon, Matador	Spray; post-emergent	Barley, wheat, canola, chickpea, faba beans, field peas, lucerne, lupins, pasture
Group 3A	Pyrethroids	Esfenvalerate	Sumi-alpha Flex	Spray; pre and post-emergent	Broadbeans, faba beans, canola, chickpea, field peas, lentils, linseed, lucerne, lupins, pasture, safflower, wheat, barley, oats, triticale
Group 4A	Neonicotinoids	Imidacloprid	Gaucho, Emerge, Senator	Seed treatment	Canola, mlover/medic, lucerne, lupins, pasture
Group 4A	Neonicotinoids	Imidacloprid & Clothianidin	Poncho Plus	Seed treatment	Canola, forage brassica, pasture
Group 1B/3A	Organophosphates / Pyrethroids	Chlorpyrifos & Bifenthrin	Pyrinex Super	Spray; bare earth and post-emergent in-crop	Canola, clover, barley, lucerne, wheat, field peas, lupins
Group 1B/3A	Organophosphates / Pyrethroids	Chlorpyrifos & Lambda-cyhalothrin	Cobalt Advanced	**Spray; post-emergent**	Wheat, barley, canola, lucerne, pasture
Group 4A/3A	Neonicotinoids / Pyrethroids	Thiamethoxam & Lambda-cyhalothrin	Crusier Opti	Seed treatment	Canola, cereals

1 Not registered in Tasmania.

SOURCE: APVMA-PUBLIC CHEMICAL REGISTRATION INFORMATION SYSTEM SEARCH (PUBCRIS), AUSTRALIAN PESTICIDES & VETERINARY MEDICINES AUTHORITY; ACCESSED MARCH 2015.

Industry chemical use and secondary chemical exposure

Examination of 172 spray records obtained from growers across New South Wales, Victoria, South Australia and Western Australia was completed in April 2015. cesar also undertook phone surveys of several broadacre advisers (agronomists and consultants). Together, this information was used to build a picture of the current approach to managing RLEM across southern Australia.

Growers and advisers generally regard RLEM as a major and common pest, typically occurring yearly or, in some locations, every two to three 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 reportedly sown with seed treated with an insecticide (especially imidacloprid). In some instances growers are not offered an alternative – 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 pastures.

Organophosphate and pyrethroid applications are either specifically targeted to RLEM or applied against several potential pests at seedling establishment. Pyrethroid 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 combination (tank mix) or repeat applications and more prominent use of organophosphates that target both mites and fleas. Approximately one-third of sprays targeting RLEM are applied prior to sowing, while 25 per cent of sprays are applied as post-sowing pre-emergent (PSPE) bare-earth treatments. About 30 per cent of insecticide sprays targeting RLEM are applied at seedling emergence.

The volume of insecticide and active ingredients used to control RLEM varies between southern-eastern (SE) and Western Australia (WA); an observation consistent with the extent and evidence of pyrethroid resistance across WA. Based on spray records and limited phone surveys, it is evident that foliar insecticides are sprayed (on average) in about 80 per cent (WA) and 20 per cent (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 pyrethroids and organophosphates either individually or as mixtures is commonplace. Application rates in WA are often targeted to multiple seedling pests and are consequently above label recommendations for RLEM. Multiple and repeated chemical applications are often applied on a yearly basis in WA.

3. CURRENT STATUS OF INSECTICIDE RESISTANCE

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

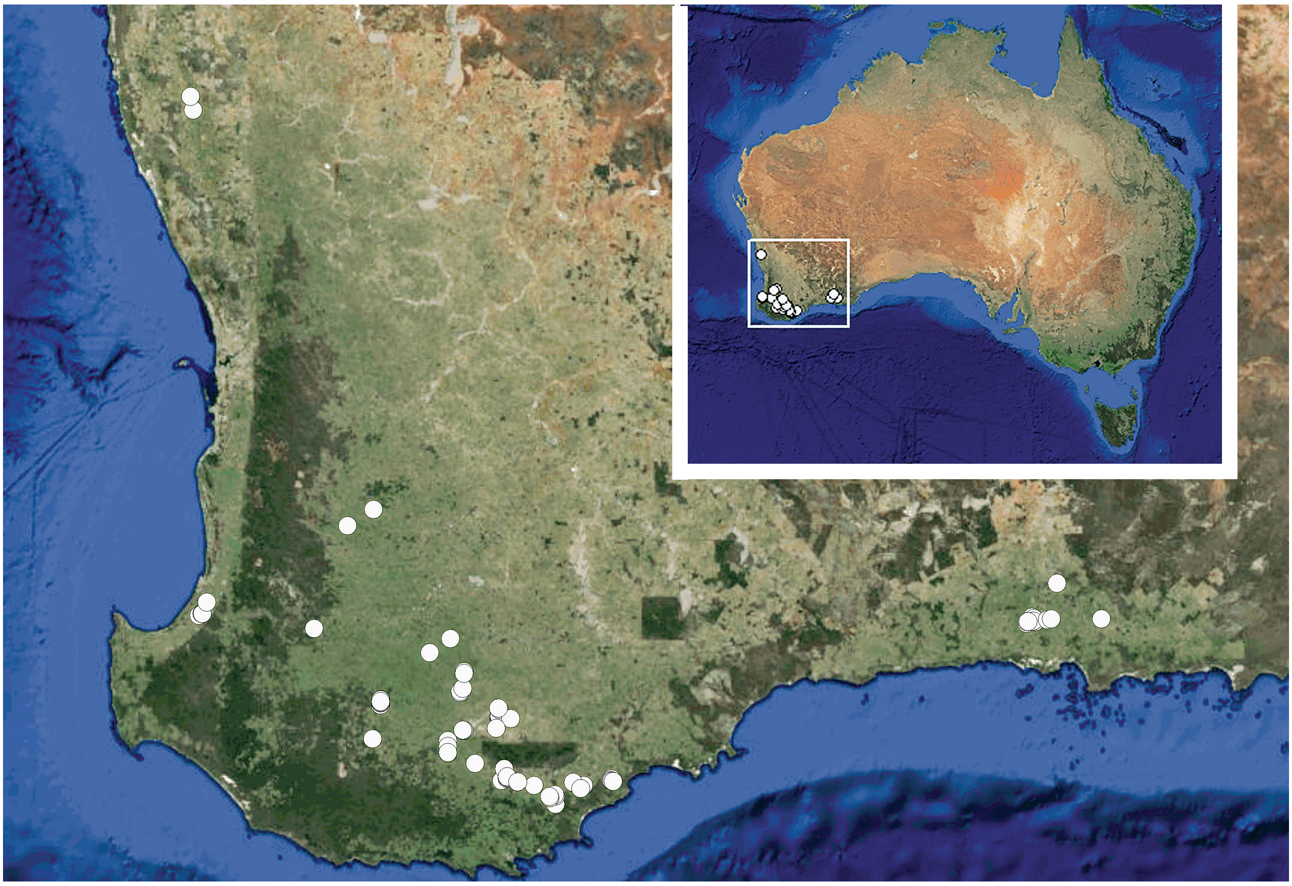
Attribute	What is known?	References
Resistance status	• Confirmed widespread and very high levels of resistance to pyrethroids across the Western Australian grainbelt. • Recently confirmed, localised, moderate levels of resistance to organophosphates in WA, including omethoate and chlorpyrifos. • Some RLEM populations resistant to omethoate have not demonstrated cross-resistance to chlorpyrifos, so chlorpyrifos may remain effective as a foliar chemical in some situations. • No resistance to any MoA confirmed outside of WA at present.	Umina 2007; Umina *et al.* 2012; P. Umina, O. Edwards, A. Lord & S. Micic (unpubl. data).
Mode of action (MoA) of resistance & cross-resistance	• Synthetic pyrethroids: para-sodium channel (mutation at *kdr* locus that causes target site modification) is the main resistance mechanism. • Organophosphate resistance is probably metabolic.	O. Edwards (unpubl. data).
Known fitness costs	• Poorly understood in Australia. Field observations and preliminary laboratory trials suggest only modest fitness costs of pyrethroid resistance but there are potentially large fitness costs associated with organophosphate resistance.	Hoffmann *et al.* 1997; X. Cheng (unpubl. data); P. Umina (unpubl. data).
Genetic basis for resistance	• Synthetic pyrethroids: *kdr* resistance shows some dominance, likely incomplete.	O. Edwards (unpubl. data); X. Cheng (unpubl. data).
Origin of resistance	• Could involve local development from rare alleles or mutation followed by gene flow rather than local selection; initial analysis seems to point to local development. • Long-distance movement of resistance alleles also likely to be important.	A. Hoffmann & O. Edwards (unpubl. data).

4. RESISTANCE MANAGEMENT AND MINIMISATION STRATEGY

The basis of this strategy is to minimise the selection pressure for resistance to the same chemical group across consecutive generations of RLEM. As the dispersal of adult mites is limited within Australia, resistance tends to remain relatively localised and spread slowly, although spread over larger distances does occasionally occur. Due to local differences in resistance levels, there is a need to implement resistance management strategies that are locally relevant. Importantly however, long-range dispersal will be mostly achieved via the diapause egg stage. Eggs are likely to be moved large distances by intense summer winds (especially on overgrazed erosion-prone soils) and through adhering to livestock, farm machinery and plant material (such as fodder shipments). It is therefore critical that strategies are implemented in all regions of Australia where RLEM are found.

We have relied upon the latest (2014) resistance surveillance activities conducted by DAFWA, **cesar** and CSIRO (S. Micic, P. Umina & O. Edwards, unpublished data). Pyrethroid resistance is relatively widespread across the WA grainbelt but not found across a large number of properties. To date, more than 50 properties in WA have been identified with RLEM that have resistance to pyrethroids. These populations occur up to 1000-plus kilometres apart. Pyrethroid resistance is absent in other states (Figure 1). In spring 2014, resistance to organophosphates (OPs) in RLEM was confirmed at a single property near Capel, WA. The current understanding of this new resistance is limited. Resistance has been identified to dimethoate/omethoate and chlorpyrifos, with even stronger cross-resistance to malathion. To date, no carbamates have been tested for cross-resistance, and the mechanism underlying OP resistance is yet to be determined.

FIGURE 1 Pyrethroid resistance in redlegged earth mite populations, 2007-2014.



White circles represent RLEM populations with confirmed resistance to pyrethroids.

SOURCE: DAFWA, **cesar** & CSIRO

TABLE 4 IPM strategies for the redlegged earth mite.

Season	Management option	Comment
Previous year (winter/spring)	Keep pastures short in early spring	Ideally graze to <1.4t/ha Food on Offer 3-4 weeks prior to the Timerite® date[1]. Heavily grazed spring paddocks will not require an insecticide spray.
	Keep fencelines clean	Spray out broadleaf weeds (especially capeweed) along fencelines of paddocks that contain RLEM.
	Use selective chemicals	Where possible avoid using organophosphates (OPs) or synthetic pyrethroids (SPs) for control of spring pests other than RLEM. For example, use pirimicarb for control of aphids and *Bt*, NPV, spinetoram or emamectin benzoate for control of caterpillars.
	Use mite-tolerant pasture species	For continuing pastures, consider selecting varieties with known mite tolerance. The pasture legume *Trifolium glanduliferum* (cv Prima gland clover) is less susceptible to RLEM feeding. Subterranean clovers – Narrikupⴲ, Bindoonⴲ and Rosabrookⴲ – may suffer less damage from RLEM than other varieties.
	Plan for less susceptible crop types	In situations where significant resistance issues exist, consider selecting crop types that are less susceptible to RLEM. Cereals are more tolerant than canola, and are typically better at compensating for early RLEM feeding damage. Some pulse crops, such as lentils and chickpeas, are not favoured by RLEM.
Pre-sowing	Control weeds 2 weeks before sowing	Control all weeds (especially capeweed & Paterson's curse) using herbicides or cultivation within paddocks and along fencelines at least 2 weeks in advance of intended sowing date. This is especially important in 'late break' years where mites have hatched and are feeding on pre-sowing weeds.
	Avoid bare earth sprays prior to mite hatch	Do not apply preventative insecticides against RLEM in seasons where crops are sown in advance of known mite-hatching events.
	Use higher seed rates	Consider higher seeding rates to allow for some mite-feeding damage and plant loss (especially in canola).
Emergence & crop establishment	Monitor and use spray thresholds	Monitor susceptible crops through to establishment using direct visual searches, and use thresholds to inform spray decisions. Avoid preventative or prophylactic sprays.
	Use border sprays if mites invade from edges	Be aware of edge effects; mites move in from weeds around paddock edges. Where RLEM are colonising crop margins and fencelines in the early stages of population development, consider a border spray with an insecticide to prevent/delay the build-up of RLEM and to retain beneficial species.

1 Timerite® is a carefully timed chemical application in spring. This approach can drastically reduce the number of 'over-summering' diapause eggs produced by RLEM. If applied correctly, Timerite® will decrease the density of mites that emerge the following autumn. Further information is available at: www.wool.com/timerite

Chemical control recommendations in Western Australia

Resistance in paddock?			
Yes, to both SPs and OPs	Yes, to SPs only	Yes, to OPs only	No
Go to Table 5A	Go to Table 5B	Go to Table 5C	Go to Table 5D

TABLE 5A Chemical control strategies for situations where redlegged earth mites have resistance to SPs and OPs – Western Australia.

SP = synthetic pyrethroid (chemical Group 3A), OP = organophosphate (chemical Group 1B); Refer to Table 7 for more detailed information on relevant insecticide groups.

Spray windows (rotate chemical groups through windows)			Rationale
1	2	3	
Pre-emergence (bare earth) and insecticide seed treatment [1,2,3]	**Early post-emergence** [1,2] (Oilseeds – up to 6-leaf) (Cereals – up to tillering) (Pulses – up to 2nd true leaf)	**Later crop stages** (Incidental RLEM control when targeting other pests)	
Seed treatment: Imidacloprid (4A) or Poncho Plus (2x4A) or fipronil (2B). **Pre-emergence/bare earth:** Do not apply.[5]	Avoid wherever possible.[5] Use chlorpyrifos (1B) only if no resistance is detected to this chemical.	Avoid the use of SPs and OPs. Instead use pirimicarb, sulfoxaflor, *Bt*, NPV, emamectin benzoate, spinetoram, indoxacarb or chlorantraniliprole.	Use of SPs (3A) for RLEM control not recommended in any spray window as resistance to this group is present. Applications of SPs will rapidly select for further resistance and will not provide adequate control of RLEM. Rotating within the OP group (1B) is an option as resistance is not always present across all OPs.[4] Growers should test the response of RLEM in a small area first. Avoid bare-earth applications so there is an option of using chlorpyrifos post-emergence, should mite numbers warrant it.[4] SPs (3A) and OPs (1B) can be used when control of pests other than RLEM is required, although this will select for further resistance in RLEM.

1 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 reducing applications from the same insecticide groups at another stage.
2 This includes applications targeted at pests other than RLEM (for example, weevils, aphids, caterpillars and other mites).
3 Bare-earth applications should be avoided, particularly in cases where Timerite® has been used the previous spring and insecticide seed treatments have been applied.
4 Some RLEM populations resistant to omethoate and dimethoate have not demonstrated cross-resistance to chlorpyrifos, so chlorpyrifos may remain effective as a foliar chemical in some situations. There are other Group 1B chemicals registered against RLEM (see Table 6), but these have not been tested against mites with resistance to organophosphates. Thus, their effectiveness and likely resistance risk remain uncertain.
5 There is an urgent need for new chemistries.

TABLE 5B Chemical control strategies for situations where redlegged earth mites have resistance to SPs only – Western Australia.

SP = synthetic pyrethroid (chemical Group 3A), OP = organophosphate (chemical Group 1B); Refer to Table 7 for more detailed information on relevant insecticide groups.

Spray windows (rotate chemical groups through windows)				Rationale
1	2	3	4	
Timerite® used in previous spring?	**Pre-emergence (bare earth) and insecticide seed treatment** [1,2,3]	**Early post-emergence** [1,2] (Oilseeds – up to 6-leaf) (Cereals – up to tillering) (Pulses – up to 2nd true leaf)	**Later crop stages** (Incidental RLEM control when targeting other pests)	
Yes, used omethoate (1B) as per label recommendation.	**Seed treatment:** Imidacloprid (4A) or Poncho Plus (2x4A) or fipronil (2B). **Pre-emergence/bare earth:** Avoid wherever possible, especially for early sowing opportunities. If unavoidable, select chlorpyrifos (1B).	Chlorpyrifos (1B), if not used at pre-emergence (Window 2). Otherwise select omethoate (1B) or dimethoate (1B).	Use pirimicarb, sulfoxaflor, *Bt*, NPV, emamectin benzoate, spinetoram, indoxacarb or chlorantraniliprole. Only use OPs if not already used at post-emergence (Window 3).	Use of SPs (3A) for RLEM control not recommended in any spray window as resistance to this group is present. Applications of SPs will rapidly select for further resistance and will not provide adequate control of RLEM. Use chlorpyrifos at pre-emergence because omethoate has been used in Timerite® spray. Rotating within OPs (1B) is an option given resistance is not always present across all OPs.[4] SPs (3A) can be used when control of pests other than RLEM is required, although this will select for further resistance in RLEM.
No	**Seed treatment:** Imidacloprid (4A) or Poncho Plus (2x4A) or fipronil (2B). **Pre-emergence/bare earth:** Avoid wherever possible, especially for early sowing opportunities. If unavoidable, select any registered OP (1B).	Any registered OP (1B). If chlorpyrifos (1B) used in Window 1, select omethoate (1B) or dimethoate (1B). OR If omethoate or dimethoate used in Window 1, select chlorpyrifos (1B).	Use pirimicarb, sulfoxaflor, *Bt*, NPV, emamectin benzoate, spinetoram, indoxacarb or chlorantraniliprole. Only use OPs if not already used at post-emergence (Window 3).	Use of SPs (3A) for RLEM control not recommended in any spray window as resistance to this group is present. Applications of SPs will rapidly select for further resistance and will not provide adequate control of RLEM. No Timerite® spray used previously therefore use any OP (1B) at pre-emergence. Rotating within the OP group (1B) is an option as resistance is not always present across all OPs.[4] SPs (3A) can be used when control of pests other than RLEM is required, although this will select for further resistance in RLEM.

See Table 5A for footnotes.

TABLE 5C Chemical control strategies for situations where redlegged earth mites have resistance to OPs only – Western Australia.

SP = synthetic pyrethroid (chemical Group 3A), OP = organophosphate (chemical Group 1B); Refer to Table 7 for more detailed information on relevant insecticide groups.

Spray windows (rotate chemical groups through windows)				Rationale
1	2	3	4	
Timerite® used in previous spring?	**Pre-emergence (bare earth) and insecticide seed treatment** [1,2,3]	**Early post-emergence** [1,2] (Oilseeds – up to 6-leaf) (Cereals – up to tillering) (Pulses – up to 2nd true leaf)	**Later crop stages** (Incidental RLEM control when targeting other pests)	
Yes, but used an SP (3A), not omethoate (1B).	**Seed treatment:** Imidacloprid (4A) or Poncho Plus (2x4A) or fipronil (2B). **Pre-emergence/bare earth:** Do not apply[5].	Any registered SP (3A) if not already used at pre-emergence (Window 2).	Avoid the use of SPs if already used in Windows 2 or 3. Instead use pirimicarb, sulfoxaflor, *Bt*, NPV, emamectin benzoate, spinetoram, indoxacarb or chlorantraniliprole.	Use of OPs (1B) for RLEM control not recommended in any spray window as resistance to this group is present. Applications of OPs will select for further resistance in RLEM. OPs (1B) can be used when control of pests other than RLEM is required, although this will select for further resistance in RLEM.
No	**Seed treatment:** Imidacloprid (4A) or Poncho Plus (2x4A) or fipronil (2B). OR Cruiser Opti (4A+3A) if SPs (3A) will not be used at post-emergence (Window 3). **Pre-emergence/bare earth:** Avoid wherever possible, especially for early sowing opportunities. If unavoidable, select any registered SP (3A).	Any registered SP (3A) if not already used at pre-emergence (Window 2).	Avoid the use of SPs if already used in Windows 2 or 3. Instead use pirimicarb, sulfoxaflor, *Bt*, NPV, emamectin benzoate, spinetoram, indoxacarb or chlorantraniliprole.	Use of OPs (1B) for RLEM control not recommended in any spray window as resistance to this group is present. Applications of OPs will select for further resistance in RLEM. OPs (1B) can be used when control of pests other than RLEM is required, although this will select for further resistance in RLEM.

See Table 5A for footnotes.

TABLE 5D Chemical control strategies for situations where redlegged earth mites have no resistance – Western Australia.

SP = synthetic pyrethroid (chemical Group 3A), OP = organophosphate (chemical Group 1B); Refer to Table 7 for more detailed information on relevant insecticide groups.

SPRAY WINDOWS (rotate chemical groups through windows)				Rationale
1	2	3	4	
Timerite® used in previous spring?	**Pre-emergence (bare earth) and insecticide seed treatment** [1,2,3]	**Early post-emergence** [1,2] (Oilseeds – up to 6-leaf) (Cereals – up to tillering) (Pulses – up to 2nd true leaf)	**Later crop stages** (Incidental RLEM control when targeting other pests)	
Yes, used omethoate (1B) as per label recommendation.	**Seed treatment:** Imidacloprid (4A) or Poncho Plus (2x4A) or fipronil (2B). OR Cruiser Opti (4A+3A) if SPs (3A) will not be used at post-emergence (Window 3). **Pre-emergence/bare earth:** Avoid wherever possible. If unavoidable, select any registered SP (3A).	Any registered OP (1B). OR Any registered SP (3A) only if SPs not used in Window 2.	Avoid the use of SPs and OPs if already used in Windows 2 and 3. Instead use pirimicarb, sulfoxaflor, *Bt*, NPV, emamectin benzoate, spinetoram, indoxacarb or chlorantraniliprole. If unavoidable, use OPs if SPs used at post-emergence (Window 3). OR Use SPs if OPs used at post-emergence (Window 3).	Avoid OPs (1B) at pre-emergence as omethoate was used in Timerite® spray.
No	**Seed treatment:** Imidacloprid (4A) or Poncho Plus (2x4A) or fipronil (2B). OR Cruiser Opti (4A+3A) if SPs (3A) will not be used at post-emergence (Window 3). **Pre-emergence/bare earth:** Avoid wherever possible. If unavoidable, select any registered SP (3A) or OP (1B), or a mixture of SP/OP (1B+3A). If applying a mixture or co-formulation, do not apply a mixture or co-formulation at post-emergence (Window 3).	Any registered OP (1B) or SP (3A). OR A single application of a mixture or co-formulation if not already used in Window 2. If one chemical group was applied in Window 2, select a different chemical group.	Avoid the use of SPs and OPs if already used in Windows 2 & 3. Instead use pirimicarb, sulfoxaflor, *Bt*, NPV, emamectin benzoate, spinetoram, indoxacarb or chlorantraniliprole. If unavoidable, use OPs if SPs used at post-emergence (Window 3). OR Use SPs if OPs used at post-emergence (Window 3).	Co-formulations or mixtures of chemicals from two groups should only be applied once per season.

See Table 5A for footnotes.

Chemical control recommendations in New South Wales, South Australia, Tasmania and Victoria

TABLE 6 Chemical control strategies for redlegged earth mite – NSW, SA, Tasmania and Victoria.

SP = synthetic pyrethroid (chemical Group 3A), OP = organophosphate (chemical Group 1B); Refer to Table 7 below for more detailed information on relevant insecticide groups.

SPRAY WINDOWS (rotate chemical groups through windows)				Rationale
1	2	3	4	
Timerite® used in previous spring?	Pre-emergence (bare earth) & insecticide seed treatment [1,2,3]	**Early post-emergence** [1,2] (Oilseeds – up to 6-leaf) (Cereals – up to tillering) (Pulses – up to 2nd true leaf)	Later crop stages (incidental RLEM control when targeting other pests)	
Yes, used omethoate (1B) as per label recommendation.	**Seed treatment:** Imidacloprid (4A) or Poncho® Plus (2x4A) or fipronil (2B) or Cruiser® Opti (4A+3A) if SPs (3A) will not be used at post-emergence (Window 3). **Pre-emergence/bare earth:** Avoid wherever possible. If unavoidable, select any registered SP (3A).	Any registered OP (1B) or Any registered SP (3A) only if SPs not used in Window 2.	Avoid the use of SPs and OPs if already used in Windows 2 & 3. Instead use pirimicarb, sulfoxaflor, *Bt,* NPV, emamectin benzoate, spinetoram, indoxacarb or chlorantraniliprole. If unavoidable, use OPs if SPs used at post-emergence (Window 3). or Use SPs if OPs used at post-emergence (Window 3).	Avoid OPs (1B) at pre-emergence as omethoate was used in Timerite® spray.
No	**Seed treatment:** Imidacloprid (4A) or Poncho® Plus (2x4A) or fipronil (2B) or Cruiser® Opti (4A+3A) if SPs (3A) will not be used at post-emergence (Window 3). **Pre-emergence/bare earth:** Avoid wherever possible. If unavoidable, select any registered SP (3A) or OP (1B), or a mixture of SP/OP (1B+3A). If applying a mixture or co-formulation, do not apply a mixture or co-formulation at post-emergence (Window 3).	Any registered OP (1B) or SP (3A) or A single application of a mixture or co-formulation. If one chemical group was applied in Window 2, select a different chemical group.	Avoid the use of SPs and OPs if already used in Windows 2 & 3. Instead use pirimicarb, sulfoxaflor, *Bt,* NPV, emamectin benzoate, spinetoram, indoxacarb or chlorantraniliprole. If unavoidable, use OPs if SPs used at post-emergence (Window 3) or Use SPs if OPs used at post-emergence (Window 3).	Co-formulations or mixtures of chemicals from two groups should only be applied once per season.

1 Where co-formulations or mixtures are used, they should be considered as two independent applications (one for each chemical group), and need to be reconciled by reducing applications from the same insecticide groups at another stage.
2 This includes applications targeted at pests other than RLEM (e.g. weevils, aphids, caterpillars, other mites).
3 Bare earth applications should be avoided, particularly in cases where Timerite® has been used the previous spring and insecticide seed treatments have been applied.

TABLE 7 Insecticide Resistance Action Committee (IRAC) mode of action (MoA) classification of insecticides and acaricides, including active ingredients registered against redlegged earth mites in Australian grain crops, and example trade names of chemical products.

IRAC MoA group	Insecticide category	Active ingredient(s)	Example trade names
GROUP 1B INSECTICIDE	Organophosphates (OPs)	Chlorpyrifos, dimethoate, methidathion, omethoate, phosmet	Strike Out®, Danadim®, Suprathion®, LeMat®, Imidan®, Pyrinex Super®[1], Cobalt Advanced[1]
GROUP 2B INSECTICIDE	Phenylpyrazoles	Fipronil	Cosmos®, Legion®
GROUP 3B INSECTICIDE	Synthetic pyrethroids (SPs)	Alpha-cypermethrin, cypermethrin, bifenthrin, gamma-cyhalothrin, lambda-cyhalothrin, esfenvalerate.	Fastac®, Scud Elite®, Talstar®, Venom®, Trojan®, Karate Zeon®, Sumi-alpha Flex®, Pyrinex Super®[1], Cobalt Advanced®[1], Cruiser® Opti[2]
GROUP 4B INSECTICIDE	Neonicotinoids	Imidacloprid, clothianidin, thiamethoxam	Gaucho®, Emerge®, Poncho® Plus, Cruiser® Opti[2]

1 Co-formulation containing Group 1B and 3A insecticides
2 Co-formulation containing Group 3A and 4A insecticides

General principles to avoid and minimise resistance development

- Avoid repeated use each season of insecticides from the same IRAC chemical mode of action against RLEM or other pests, as this will increase selection pressure for resistance development, not only in RLEM, but also in other species such as green peach aphid and diamondback moth.
- Consider the impact on target and non-target pests and beneficial invertebrates when applying insecticide sprays. Where possible, use target-specific 'soft chemicals' especially in paddocks with resistant RLEM. For aphids, this includes pirimicarb (canola, pastures, cereals & some pulses) and sulfoxaflor (canola and cereals). For caterpillars, use *Bt* (cereals, canola and pulses), NPV (canola, cereals and some pulses), emamectin benzoate (canola and pulses), spinetoram (canola and forage brassicas), indoxacarb (some pulses) and chlorantraniliprole (some pulses).
- Identify mite species correctly to ensure the most effective insecticide and rate is used. Misidentification and incorrect insecticide selection results in poor control and contributes to selection for resistance.
- Assess mite and beneficial populations over successive checks to determine if chemical control is warranted. Use economic spray thresholds where available and do not spray if pest pressure is low (for example, in situations of continuous cereal rotations or following a pulse crop that has been kept free of weeds).
- If spraying autumn pastures, aim to control the first generation of mites before adults lay eggs (within 3 weeks of mite appearance). This works well in years where there is a mass hatching in a single time interval. Chemical sprays do not kill mite eggs – apply sprays when most mites have emerged.
- Avoid repeated applications of products from the same insecticide group on RLEM and other pests in the same paddock.
- Do not re-spray a paddock in the same season where a known spray failure has occurred using the same product or another product from the same insecticide group, or if a spray failure has occurred where the cause has not been identified.
- Apply perimeter insecticide sprays when infestations are concentrated on the edge of fields.
- Control alternate host plants, especially broadleaf weeds such as capeweed and Paterson's curse/salvation Jane.
- In pastures, heavy grazing or cutting for hay in early spring will reduce mite numbers;
- Comply with all directions for use on product labels.
- Ensure spray rigs are properly calibrated and sprays achieve good coverage, particularly in crops with a bulky canopy.
- Where resistance is known to be present, implement steps to limit the movement of resistant mites (and mite eggs) through the transport of hay/silage, farm machinery and livestock into paddocks/farms without resistance.

5. 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.

Gaul 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.

McDonald G, Umina PA, MacFadyen S, Mangano P, and Hoffmann AA. 2014. 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. 2007. Biology and control of *Halotydeus destructor* (Tucker) (Acarina: Penthaleidae): a review. *Experimental and Applied Acarology* 21: 195-224.

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 Physiology* 51: 717-726.

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.

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.

Valenzuela I and Hoffmann AA. 2015. Effects of aphid feeding and associated virus injury on grain crops in Australia. *Austral Entomology* 54: 292-305.

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.

GRDC™

GRAINS RESEARCH & DEVELOPMENT CORPORATION