



Article

Unlocking Industry Views for Effective Redlegged Earth Mite Resistance Management

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Abstract

Insecticide resistance is a growing threat to global food security, with several major pests in Australian broad-acre systems already showing high resistance levels. Integrated Pest Management (IPM) can reduce insecticide reliance and slow resistance evolution, yet adoption remains low. Using the redlegged earth mite (*Halotydeus destructor*, RLEM) as a case study, we examined how knowledge gaps and risk attitudes influence insecticide use and broader pest management. An online survey of grain growers and advisors in RLEM-affected regions revealed that, despite widespread resistance to synthetic pyrethroids and organophosphates, and most respondents identifying with an IPM mindset, these insecticides remain frequently used. Advisors demonstrated greater overall knowledge than growers, but substantial gaps persisted across both groups, including awareness of field resistance and familiarity with national resistance management guidelines. Risk aversion showed a stronger and more consistent influence on management decisions than knowledge, shaping both growers' and advisors' recommendations. These findings highlight demographic and attitudinal factors that can undermine resistance management. While centred on RLEM, the behavioural drivers identified here likely influence pest control decisions across a range of pest species and farming systems.

Keywords: insecticide resistance; integrated pest management; cropping systems; risk attitude; behaviour change



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1. Introduction

Insect and other invertebrate pests can evolve resistance to chemical insecticides under conditions of high selection pressure, such as repeated applications of chemicals with the same Mode of Action (MoA) group [1]. Globally, increasing insecticide resistance due to overuse of chemicals threatens food production [2]. In Australian broad-acre agriculture, extensive insecticide use combined with a limited number of available MoA groups has contributed to the evolution of resistance in several key pests [3]. This issue is expected to intensify due to stricter chemical regulations, climate change, and the introduction of pests already resistant to available insecticides [4,5]. While the concern around the need to

reduce insecticide use and rely on more sustainable strategies is not new [6], the additional pressures of insecticide resistance underscore the need for pest management strategies that reduce chemical reliance while maintaining productivity.

Insecticide resistance in Australia is frequently driven by reactive pest management, including prophylactic insecticide applications, rather than preventative approaches [3,7]. When resistance evolves, the effectiveness of a chemical declines, potentially compromising the viability of entire chemical groups for specific pests, which is a significant concern when options are limited [8]. Integrated Pest Management (IPM) offers a framework to reduce insecticide inputs via the strategic use of targeted insecticides alongside non-chemical control methods. By limiting the repeated use of chemicals, IPM can underpin effective resistance management [9], with potential economic benefits outweighing implementation costs [7].

Despite its demonstrated benefits, adoption of IPM and resistance management strategies in farming communities is often slow. Growers may perceive these approaches as more complex, knowledge-intensive, or costly than conventional chemical practices [10]. Effective IPM requires an understanding of pest biology and ecology [11], and decision-making is shaped by both growers and advisors, whose recommendations are influenced by employment context, industry connections, and attitudes towards sustainable practices [12–15]. Growers' own experiences, as well as those of their local networks, further influence management choices, highlighting the importance of understanding context-specific knowledge and attitudes [16]. Psychosocial factors, particularly attitude towards risk, social norms, and internal motivations, play a central role in these decisions [17,18], especially where economic risk is concerned [19]. Risk attitude is strongly associated with insecticide use and the adoption of sustainable management practices [20–23], with more risk-averse growers often relying on prophylactic insecticide applications as “insurance” against pest damage, even when pest risk is low [24,25]. Such perceptions may also limit engagement with decision support tools for pest management [26], underscoring the need to better understand how attitude towards risk and knowledge interact to influence management decisions and to design supports that reduces unnecessary insecticide use.

The redlegged earth mite (*Halotydeus destructor*, RLEM) is a key pest in Australian winter crops and pastures [27,28]. Limited chemical MoA groups, combined with widespread prophylactic use of insecticides, have led to significant resistance issues. Resistance was first detected in 2006 [29], and large areas of western and south-eastern Australia now harbour populations resistant to pyrethroids, organophosphates, or both [30]. In response, a National Insecticide Resistance Management Strategy for RLEM was developed in 2016 and later updated in 2018 [31], emphasising judicious chemical use to maintain insecticide efficacy.

This study aimed to understand how grower and advisor knowledge and risk aversion influence decisions regarding RLEM chemical management, and whether these factors differ across age groups, industries, career stages, and regions. The hypothesis was that both knowledge and attitude towards risk vary among demographic groups and significantly influence management practices. To address this, an online survey was conducted to capture RLEM management practices, pest knowledge, and risk aversion among growers and advisors across eastern and western Australian growing regions.

2. Methods

2.1. Theoretical Framework

This study was guided by descriptive and prescriptive decision theories. Descriptive decision theory examines how individuals actually make decisions, considering cognitive, psychological, and social influences [32]. Prescriptive decision theory uses insights from

descriptive approaches to design interventions that help people make better-informed decisions. Together, these frameworks allowed us to investigate how grower knowledge and risk attitudes influence insecticide use decisions and how management guidelines can be tailored to support optimal pest control.

2.2. Survey Design and Distribution

An online survey was developed and distributed to growers and advisors in eastern and western Australian regions where RLEM occurs. Participants were required to have prior experience managing or advising on RLEM. The survey comprised five sections: (1) demographics; (2) insecticide use patterns; (3) management practices and attitudes towards risk; (4) knowledge of RLEM biology and resistance; and (5) community connectivity.

Demographics included age, career stage, occupation, primary enterprise type, and postcode. Initial screening ensured participants had encountered RLEM. Grower and advisor questions were adapted for relevance, totalling 24 questions each, with formats including multiple-choice, matrix, and Likert-scale items. The survey took approximately 10 min to complete and was administered via Qualtrics between October 2021 and February 2022.

Survey recruitment utilised newsletters, social media, partner networks, and media releases through the Australian Grains Research and Development Corporation and Meat & Livestock Australia. Participants were offered free access to RLEM training materials as an incentive to complete the survey. A copy of the survey questions is provided in Supplementary Materials File S1. This paper presents analyses based on a subset of the survey data, comprising the majority of responses collected.

3. Analysis

We primarily used quantitative approaches to analyse the survey data. This included developing indices of risk aversion and knowledge of RLEM from groups of related questions and applying statistical models to categorical responses and to associations between the indices and insecticide spray use. Responses were excluded if the participant was younger than 18 years, did not agree to the initial terms, did not identify as a grower or advisor, or had no prior experience with RLEM. We retained data from 16 growers and 7 advisors who submitted incomplete surveys, provided they met the above inclusion criteria, had completed the demographic section, and had completed >50% of the remaining survey questions. Responses from growers and advisors were analysed separately, with geographic location grouped into West (comprising Western Australia) and East regions (comprising South Australia, Victoria, the Australian Capital Territory, New South Wales and Tasmania), noting that RLEM does not occur in Queensland or the Northern Territory. Incomplete surveys were analysed in the same manner as completed surveys; for any given analysis, unanswered questions were treated as missing values, resulting in a reduced sample size for that specific question only.

3.1. Knowledge Index (KI)

A knowledge index (KI) was developed based on responses to seven questions related to identification, pest lifecycle, and insecticide resistance in RLEM. These questions were as follows: (1) Based on your current knowledge, has RLEM evolved resistance to synthetic pyrethroids (foliar)? (2) Based on your current knowledge, has RLEM evolved resistance to organophosphates (foliar)? (3) Based on your current knowledge, has RLEM evolved resistance to diafenthiuron (foliar)? (4) Based on your current knowledge, has RLEM evolved resistance to neonicotinoids (seed treatment)? (5) Based on your current knowledge, has RLEM evolved resistance to fiproles (seed treatment)? (6) Indicate which species you think is RLEM (Note: respondents were presented with photos of six mite species found in

Australian crops and pastures, one of which was RLEM). (7) Indicate which of the following you think is the correct lifecycle for RLEM (Note: respondents were presented with lifecycle images of four mite species found in Australian crops and pastures, one of which was RLEM). For questions on identification and lifecycle, correct responses were scored 25 and incorrect responses scored 0. For questions on whether RLEM had evolved resistance to synthetic pyrethroid and organophosphate insecticides, 'Yes' responses were scored 10, while 'No' or 'Unsure' were scored 0. For questions on whether RLEM had evolved resistance to diafenthiuron, neonicotinoids, and fiproles, 'No' responses were scored 10, while 'Yes' and 'Unsure' were scored 0. All scores were then summed to produce a total KI ranging from 0 to 100.

3.2. Risk Aversion Index (RAI)

Risk attitude refers to how individuals weigh costs, benefits, and the context of risk when making decisions [33]. To compare attitudes with management practices, we developed a risk aversion index (RAI) that converted qualitative responses into quantitative scores. Grower respondents rated their agreement with the following statements: (1) I am willing to take risks when it comes to farming. (2) I am cautious about adopting new ideas and farm practices. (3) A new farm practice must be proven on other farms or trials before I will use it. (4) I am concerned about economic loss as a result of invertebrate pest damage. Advisor respondents rated their agreement with the following statements: (1) I am cautious about advising new ideas and farm practices. (2) I avoid risky options when providing advice to clients. (3) A new farm practice must be proven on other farms or trials before I advise a client to use it. (4) I am concerned about losing a client if my advice leads to a loss of their profit. Responses of 'Strongly agree', 'Somewhat agree', 'Neither agree nor disagree', 'Somewhat disagree', and 'Strongly disagree' were scored as 100, 50, 0, −50, and −100, respectively, except for the positively framed 'Willingness to take risks' statement, which was reverse-scored (−100 to 100). All scores were summed and divided by four to produce a risk aversion index (RAI) score ranging from −100 to 100.

3.3. Statistical Modelling

We used multinomial logistic models to analyse survey questions with categorical responses, including demographics, insecticide spray frequency, confidence in management decisions, and IPM mindset, noting IPM mindset was self-reported by both growers and advisors by answering the question: 'In your view, how often do you employ an Integrated Pest Management (IPM) mindset to manage pests?'. The core model was specified as

$$Y_{i,1:k} \sim \text{Multinomial}(p_i, N)$$

where $Y_{i,1:k}$ was the count of responses of respondent i for each of the k categories; p_i was the vector of probabilities for each of the k categories; and N was the number of trials, which was equal to 1. The priors for p_i were specified as

$$p_i \sim \text{Dirichlet}(\alpha_{1:k})$$

where α was the vector or k parameters for the Dirichlet distribution.

We used general and generalised linear models to assess the effect of age, region, industry and career stage on insecticide spray use, risk aversion, and RLEM knowledge, as well as the effect of prior economic loss caused by RLEM on attitude towards risk. The core models were specified as

$$S_i \sim \text{Bernoulli}(p_i) [\text{Spraying models} \mid \text{growers}]$$

$$AS_i \sim \text{Binomial}(p_i, N_i) \text{ [Spraying models | advisors]}$$

$$RAI_i \sim \text{Normal}(\mu_i, \tau) \text{ [Risk aversion models]}$$

$$KI_i \sim \text{Binomial}(p_i, N_i) \text{ [RLEM knowledge models]}$$

where S_i was the Boolean vector indicating whether growers i indicated a spraying frequency of once or more per season ($S = 1$) or less than once per season ($S = 0$); AS_i was the vector indicating the percentage of times advisors i advised their client to spray; RAI_i and KI_i were the values of the RAI and KI scores, respectively; p_i was the probability of spraying once or more per season (grower models) or the probability of advising clients to spray (advisor models); μ_i was the mean RAI_i ; $\tau = 1/sd^2$, with sd given a Uniform (0, 100) prior; and N was the number of trials, which was equal to 100.

A treatment fixed effect *treat* was added to the linear predictors:

$$\text{logit}(p_i) = \text{treat}[\text{category}_j] \text{ [Spraying models and RLEM knowledge models]}$$

$$\mu_i = \text{treat}[\text{category}_j] \text{ [Risk aversion models]}$$

where category_j was an integer indexing the demographic variable's categories; and the treatment fixed effects *treat* were given Normal (0, 0.001) priors.

We used variations of the Bernoulli- and binomially distributed generalised linear models described above to assess the effect of risk aversion and RLEM knowledge on insecticide spray use. The core models were specified as

$$S_i \sim \text{Bernoulli}(p_i)$$

$$AS_i \sim \text{Binomial}(p_i, 100)$$

The linear predictors were specified as

$$\text{logit}(p_i) = \alpha + \beta \times RAI_i \text{ [Risk aversion model]}$$

$$\text{logit}(p_i) = \alpha + \beta \times KI_i \text{ [RLEM knowledge model]}$$

where α was the intercept parameter; β was the effect (i.e., slope) parameter; and RAI_i and KI_i were the mean = 1, $sd = 0$ standardised value of RAI and KI scores, respectively. Priors for α and β were specified as Normal (0, 0.001).

We then used the estimated intercept and effect parameters to draw predictions across a reasonable range of the RAI (−40 to 60) and KI (growers: 10 to 90; advisors: 30 to 90) gradients.

We estimated model parameters with Bayesian inference, using Markov Chain Monte Carlo simulations to draw samples from the parameters' posterior distributions. We implemented models in JAGS [34], via the R package jagsUI version 1.4.2 [35]. We used three chains of 5000 iterations, discarding the first 500 iterations as burn-in. We assessed acceptable convergence by visually inspecting the chains and verifying values of the Gelman–Rubin statistic fell below 1.1 [36].

4. Results

A total of 273 survey responses were received, of which 83 were deemed ineligible and removed, leaving 93 grower and 97 advisor responses.

4.1. Demographics

Comparing demographic groups as a proportion of respondents (Figure 1; Table S1) revealed statistical differences among age brackets, with the 30–49-year-old category being

the largest. Notably, there were on average 2.92 times more advisors than growers in the youngest age bracket and no advisors older than 70 years of age (Figure 1a). Geographically, the East region contributed more respondents than the West, with 2.13 and 3.27 times more growers and advisors, respectively (Figure 1b). Industry representation also differed significantly. For growers, the 'Mixed' category had 1.30 and 2.68 times more respondents than 'Meat and Livestock' and 'Grains', respectively, and the 'Meat and Livestock' category had 2.06 times more than 'Grains' (Figure 1c). A similar trend was observed among advisors, with most respondents servicing growers with 'Mixed' farming enterprises. Career stage distribution was skewed towards 'Late' stage respondents. Growers in this category were 5.16 and 7.98 times more numerous compared to 'Mid' and 'Early' stage, respectively. 'Late' stage advisors were 3.10 and 4.64 times more numerous than their 'Early' and 'Mid' counterparts, respectively (Figure 1d). Among the advisor respondents, 11% worked as sole traders and 89% worked for a company.

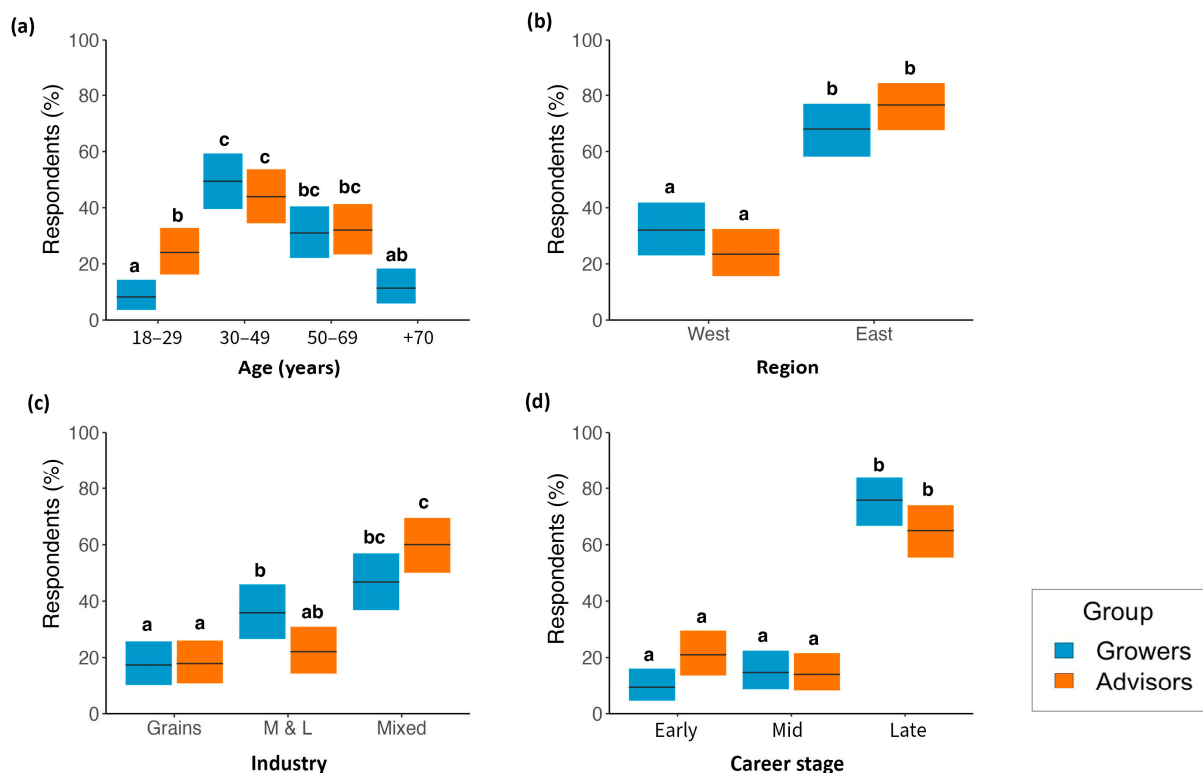


Figure 1. Summary of the survey respondent demographics by (a) age, (b) region, (c) industry, and (d) career stage. Lowercase letters indicate significant differences within each plot. For industry categories, Grains = grain crops only; M&L = meat and livestock only; Mixed = grain crops and meat and livestock. For career stage, Early = 0–5 years of experience; Mid = 6–10 years of experience; Late = >10 years of experience. Shaded areas represent 95% confidence intervals.

4.2. Grower and Advisor Knowledge

When presented with six photos of different mite species and asked to identify RLEM, 79% of growers and 95% of advisors responded correctly. However, when presented with four diagrams of different lifecycles, 78% for advisors responded correctly but only 48% of growers responded correctly. Knowledge of insecticide resistance in RLEM was also variable between growers and advisors, and this differed among insecticide groups (Table 1). For insecticides without current resistance in RLEM (diafenthiuron, fiproles, and neonicotinoids), growers correctly identified resistance status in only 8–17% of cases, with 66–74% of respondents being unsure. Advisors were slightly more knowledgeable, correctly identifying resistance status in 14–20% of cases. For insecticides with established resistance

in RLEM (synthetic pyrethroids and organophosphates), only 31% of growers correctly identified the resistance status, compared to 71% and 72% for advisors, respectively.

Table 1. Percentage of growers and advisors who responded ‘No’, ‘Unsure’, or ‘Yes’ when asked whether RLEM has evolved resistance to the insecticides registered to control this pest in Australia. The correct answers for each insecticide are shaded in green.

Insecticides	Grower Responses			Advisor Responses		
	No	Unsure	Yes	No	Unsure	Yes
Diafenthiuron	8%	70%	9%	14%	76%	4%
Fiproles	11%	74%	1%	20%	74%	1%
Neonicotinoids	17%	66%	3%	18%	64%	13%
Organophosphates	6%	48%	31%	6%	16%	72%
Synthetic pyrethroids	9%	46%	31%	4%	20%	71%

Knowledge index (KI) scores developed for each respondent were consistently higher among advisors compared with growers, regardless of age, region, industry, and career stage (Figure 2; Table S2). Respondents from the West had higher KI scores than those from the East, on average 1.17 times higher for growers and 1.13 times higher for advisors (Figure 2b). Among growers, those with ‘Mixed’ farming enterprises had KI scores 1.51 times higher than ‘Meat and Livestock’ (Figure 2c). ‘Late’ career stage respondents had higher KI scores than ‘Early’ career respondents for both growers (1.39 times) and advisors (1.16 times) (Figure 2d).

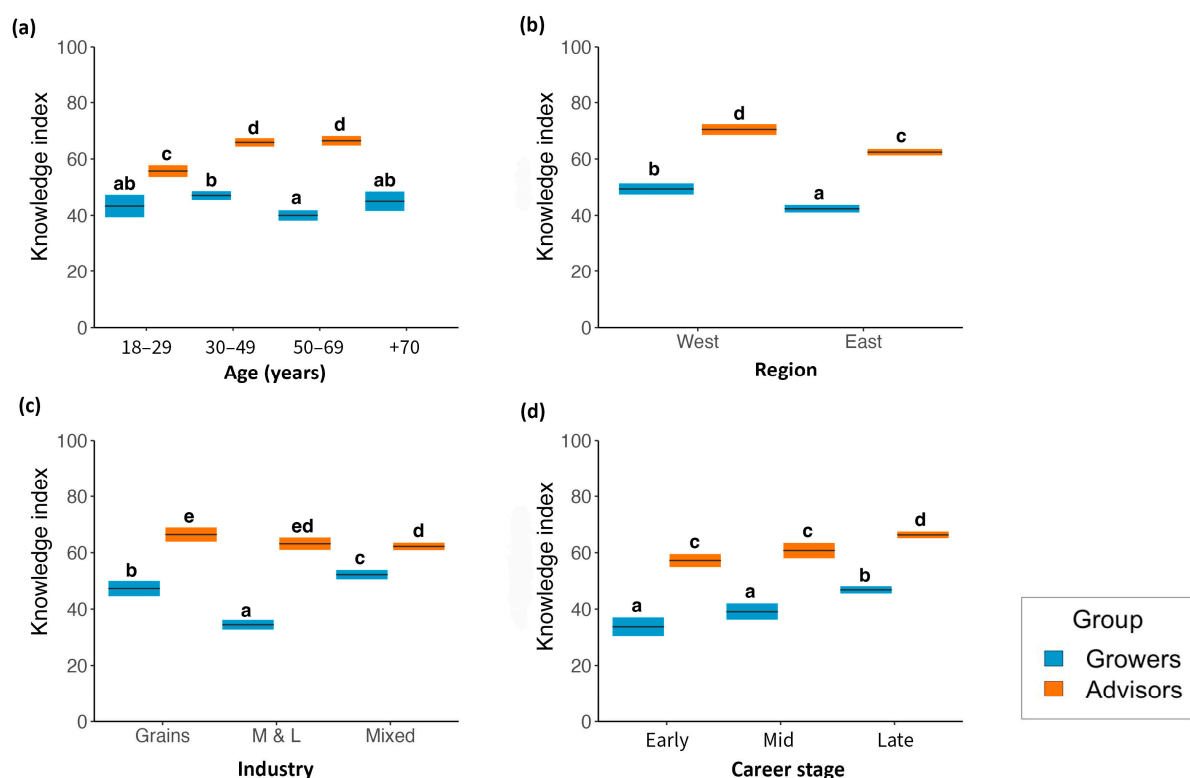


Figure 2. Knowledge index (KI) scores of growers and advisors by (a) age, (b) region, (c) industry, and (d) career stage. Lowercase letters indicate significant differences within each plot. For industry categories, Grains = grain crops only; M&L = meat and livestock only; Mixed = grain crops and meat and livestock. For career stage, Early = 0–5 years of experience; Mid = 6–10 years of experience; Late = >10 years of experience. Shaded areas represent 95% confidence intervals.

Although not part of our calculation of KI, familiarity with the National RLEM Insecticide Resistance Management Strategy was explored as another way to understand

the knowledge base of growers and advisors. Only 14% of advisors and 4% of growers reported being ‘Very familiar’ or ‘Extremely familiar’ with this strategy. In total, 54% of advisors and 53% of growers were ‘Not familiar’ or only ‘Slightly familiar’ with it.

4.3. Insecticide Use Patterns

Growers reported variable frequencies of foliar insecticide applications targeting RLEM. A total of 5% sprayed insecticides several times per year, 35% annually, 25% every 2–3 years, 9% every 4–5 years, 14% rarely, 11% never, and 1% were unsure. Overall, demographics had relatively minimal impact on spraying frequency, although growers aged 70+ tended to spray less than their younger counterparts. Although not significantly different, growers from the West region reported spraying more frequently than those from the East, those with ‘Mixed’ farming enterprises reported spraying more frequently than ‘Grains’ and ‘Meat and Livestock’ growers, while ‘Early’ career growers reported spraying less frequently than ‘Mid’ and ‘Late’ career growers (Figure 3; Table S3).

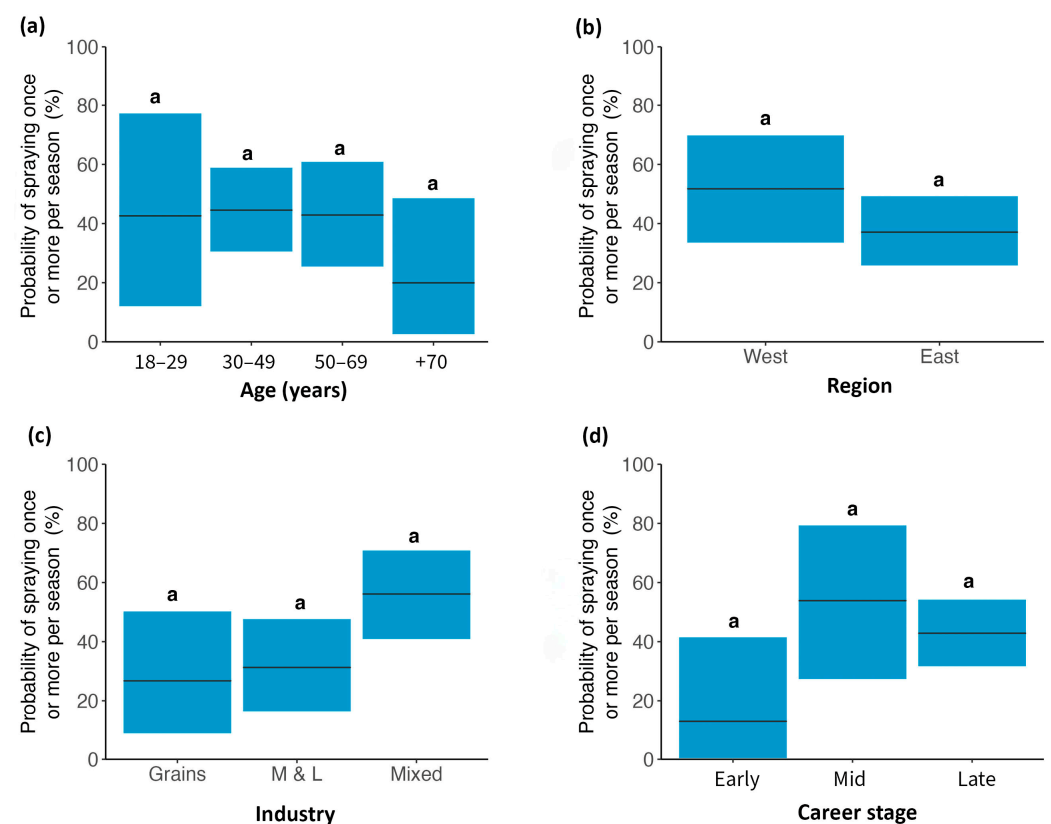


Figure 3. Probability of growers spraying foliar insecticides to control RLEM once or more per season by (a) age, (b) region, (c) industry, and (d) career stage. Lowercase letters indicate significant differences within each plot. For industry categories, Grains = grain crops only; M&L = meat and livestock only; Mixed = grain crops and meat and livestock. For career stage, Early = 0–5 years of experience; Mid = 6–10 years of experience; Late = >10 years of experience. Shaded areas represent 95% confidence intervals.

Over half of the advisors ($n = 52$) reported recommending insecticide foliar applications to control RLEM in at least 70% of client consultations, with 33 advising spraying in 70–80% of cases and 19 in 90–100% of cases. Only one advisor indicated they would never recommend spraying insecticides to control RLEM. Overall, the likelihood of recommending sprays was high across all demographic groups, with significant differences between age categories, regions, industries, and career stages (Figure 4; Table S4). Younger advisors (18–29 years old) were 1.06 and 1.34 times more likely to recommend spraying for RLEM

than those aged 30–49 and 50–69, respectively (Figure 4a). Advisors from the West region were 1.24 times more likely to recommend spraying for RLEM than advisors from the East region (Figure 4b). Advisors in the ‘Grains’ category were 1.15 and 1.10 less likely to recommend spraying than those in the ‘Mixed’ and ‘Meat and Livestock’ categories, respectively (Figure 4c). ‘Late’ career advisors were around 1.2 times less likely to recommend spraying than ‘Early’ and ‘Mid’ career advisors (Figure 4d). Business structure (‘Company’ versus ‘Sole trader’) did not influence the likelihood of recommending spraying insecticides for RLEM (Figure 4e).

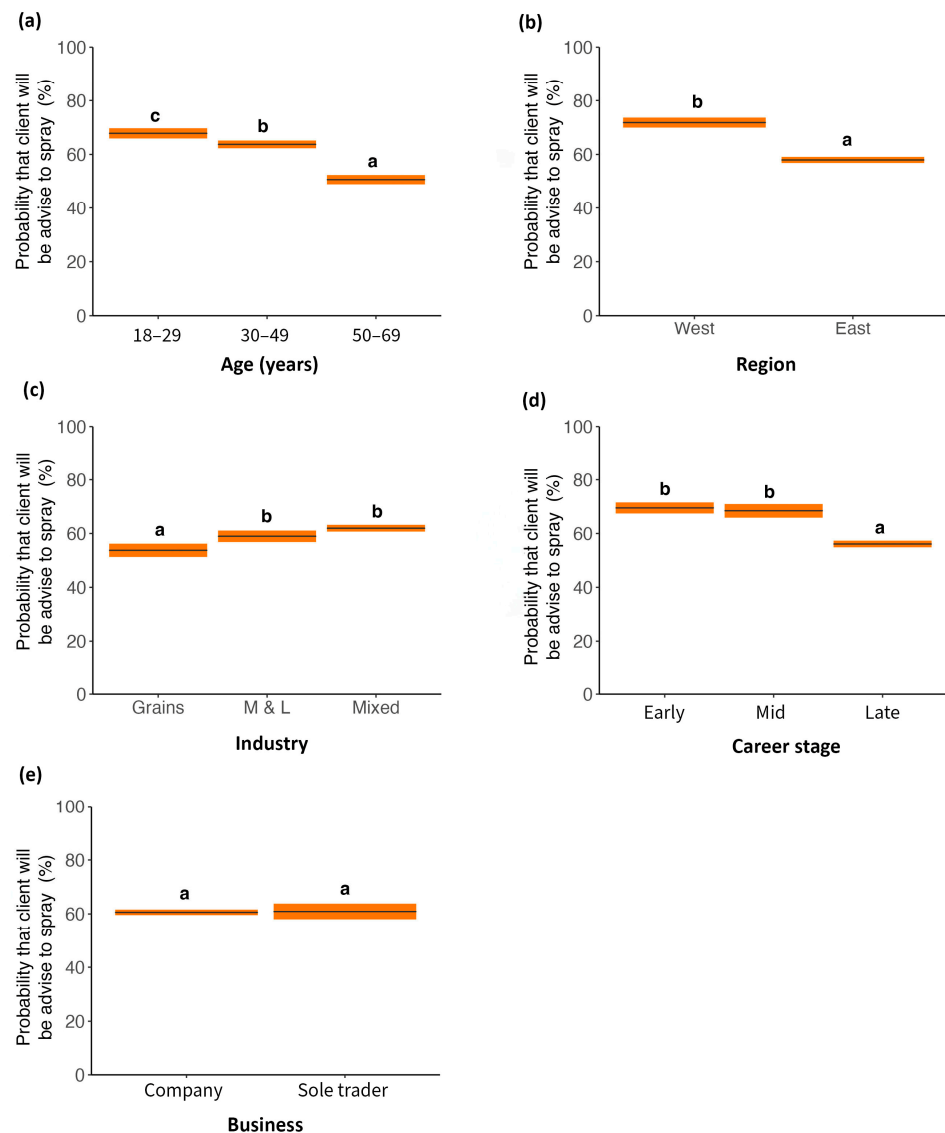


Figure 4. Probability of advisors recommending their grower clients spray foliar insecticides to control RLEM by (a) age, (b) region, (c) industry, (d) career stage, and (e) business. Lowercase letters indicate significant differences within each plot. For industry categories, Grains = grain crops only; M&L = meat and livestock only; Mixed = grain crops and meat and livestock. For career stage, Early = 0–5 years of experience; Mid = 6–10 years of experience; Late = >10 years of experience. Shaded areas represent 95% confidence intervals.

Growers reported how frequently they used different insecticides for RLEM control, while advisors reported how often they recommended different insecticides. Both groups most commonly reported using or advising the use of synthetic pyrethroids, organophosphates, and neonicotinoids, whereas fiproles and diafenthiuron were rarely used or advised (Figure S1; Table S5). Spraying frequencies differed between regions, particularly for syn-

thetic pyrethroids and organophosphates (Figure S2, Table S6). Growers from the West reported ‘Often’ using synthetic pyrethroids 2.90 times more frequently than growers from the East, while growers from the West reported ‘Never’ using organophosphates 4.20 times less frequently than those from the East. Use of diafenthiuron also differed between regions, with growers from the East reporting ‘Sometimes’ using this insecticide 3.42 times more than growers from the West (Figure S2, Table S6).

4.4. Factors Influencing Decision Making

We examined the relationship between KI and management decisions for RLEM. For growers, higher KI scores were associated with a slight reduction in the likelihood of spraying insecticides once or more per season, whereas no such relationship was observed for advisors (Figure 5; Table S7).

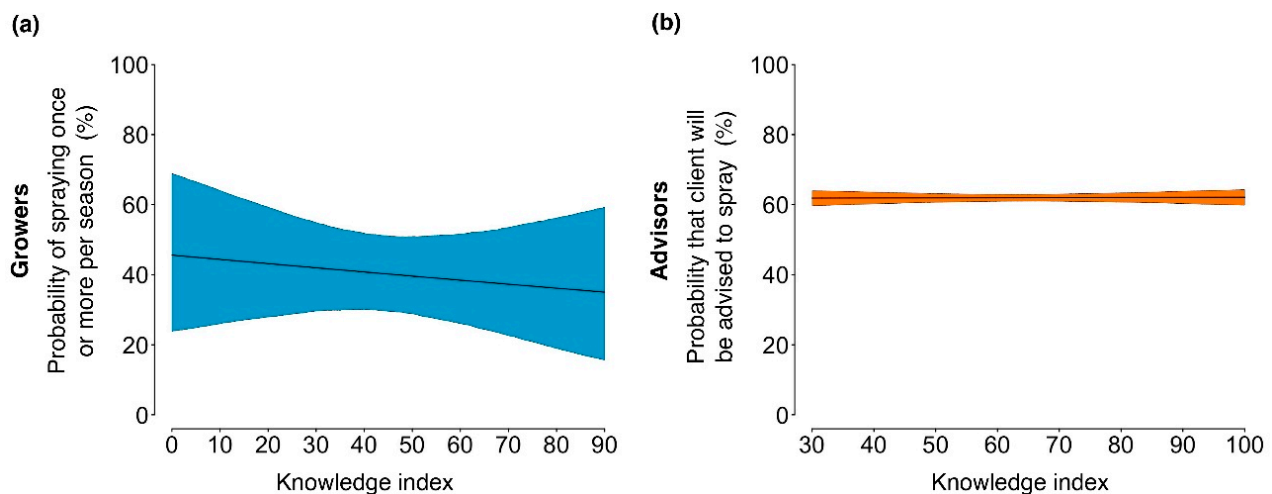


Figure 5. Relationship between respondents’ knowledge index (KI) scores and the probability of (a) growers spraying foliar insecticides to control RLEM once or more per season, or (b) advisors recommending their grower clients spray foliar insecticides to control RLEM. The knowledge index ranges from 0 to 100. Shaded areas represent 95% confidence intervals.

Growers reported marginally lower confidence in RLEM management decisions than advisors, who were more likely to express high levels of confidence (Figure 6; Table S8). Self-reported adoption of an IPM mindset was generally low and did not differ significantly between growers and advisors (Figure 7; Table S9). However, discrepancies emerged between stated mindset and reported behaviours. Among advisors who indicated they ‘Always’ or ‘Often’ employed an IPM mindset, 42% still recommended foliar insecticides to control RLEM to more than 70% of their clients. This proportion rose to 77% among advisors with lower IPM mindsets. Similarly, of the growers who reported frequently employing an IPM mindset, 30% reported spraying foliar insecticides for RLEM annually and a further 26% reported spraying insecticides for RLEM every 2–3 years.

Advisors cited a broader range of factors influencing decisions about insecticide use for RLEM control than growers (Figure S3). Advisors placed more weight on ‘Other pests in the paddock’ (71% vs. 36%), ‘Cost of control measures’ (62% vs. 40%) and the ‘Evolution of local resistance’ (66% vs. 44%).

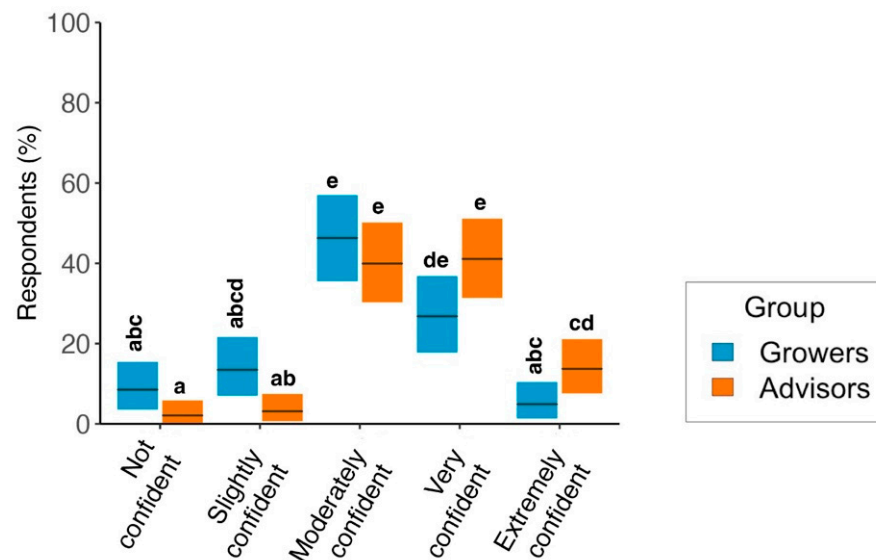


Figure 6. Percentage of growers and advisors self-reporting their confidence levels in making RLEM management decisions. Lowercase letters indicate significant differences and shaded areas represent 95% confidence intervals.

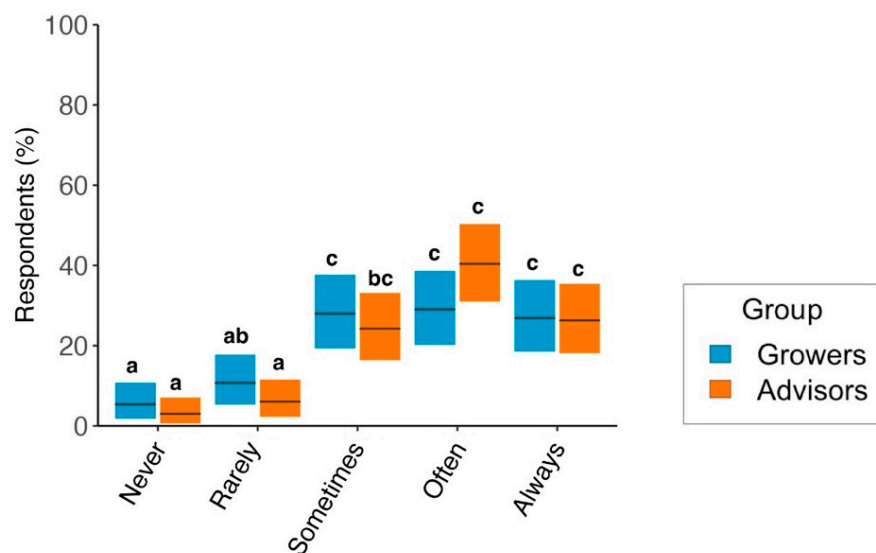


Figure 7. Percentage of growers and advisors self-reporting their frequency of employing an Integrated Pest Management (IPM) mindset. Lowercase letters indicate significant differences and shaded areas represent 95% confidence intervals.

4.5. Risk Aversion

Growers were more likely than advisors to express concerns about economic losses as a result of pest damage but also reported a greater willingness to take risks in farming. Advisors, in contrast, were less willing to take risks and were more cautious about adopting new farm practices than growers (Figure 8).

Overall, advisors scored higher on the risk aversion index (RAI) than growers across all demographic categories. RAI did not vary significantly with age, location, career stage, or industry sector within either group (Figure S4; Table S10). RAI was positively associated with growers' likelihood of spraying foliar insecticides to control RLEM once or more per season, as well as advisors' likelihood of recommending their grower clients spray insecticides to control RLEM (Figure 9; Table S11). There was no overall difference in RAI scores between growers who reported experiencing a significant economic loss from RLEM in the past 5 years and growers that have not experienced such a loss (Table S12). However,

there was a positive relationship between advisors' RAI scores and the percentage of their grower clients that have experienced a significant economic loss from RLEM in the past 5 years (Figure S5; Table S13).

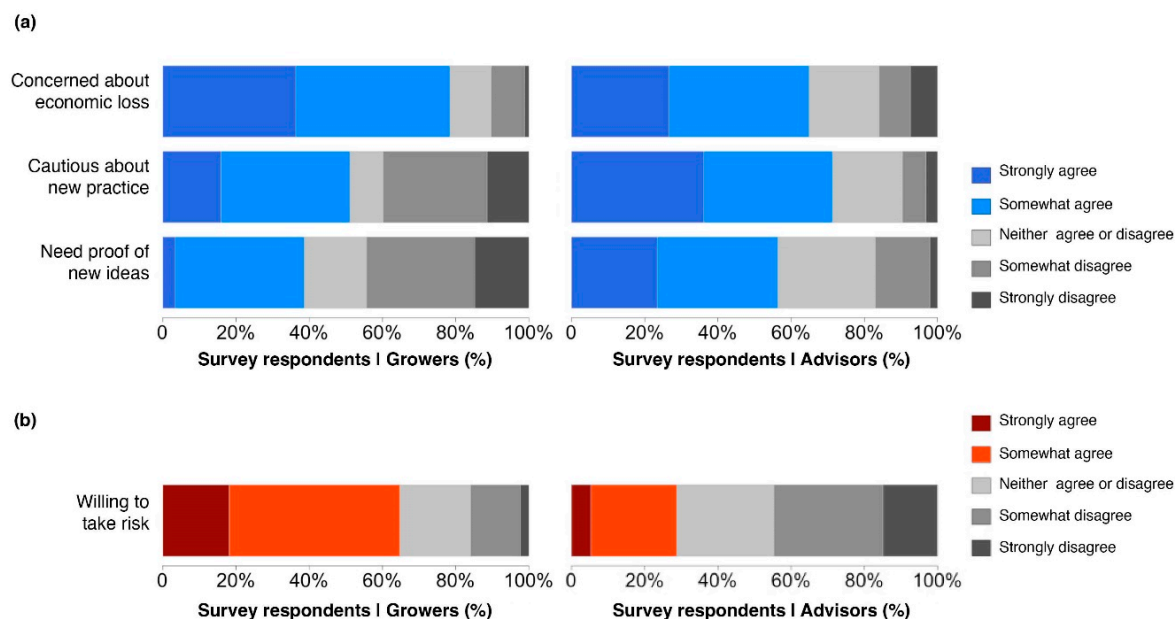


Figure 8. Percentage of growers and advisors agreeing or disagreeing with statements related to risk attitudes, shown for (a) negatively framed and (b) positively framed statements.

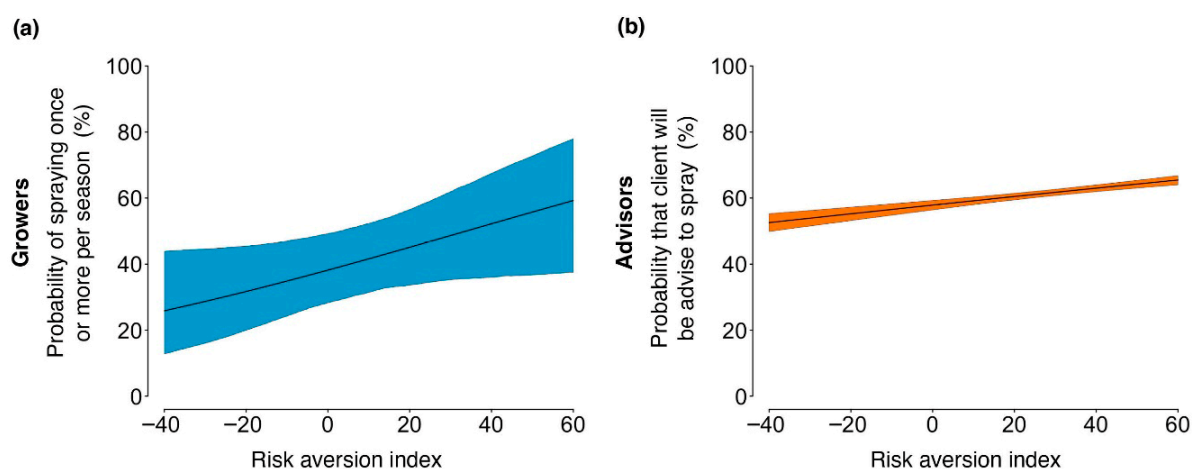


Figure 9. Relationship between respondents' risk aversion index (RAI) scores and the probability of (a) growers spraying foliar insecticides to control RLEM once or more per season, or (b) advisors recommending their grower clients spray foliar insecticides to control RLEM. The risk aversion index ranges from −100 to 100. Shaded areas represent 95% confidence intervals.

5. Discussion

This study provides new insights into how knowledge and risk aversion shape management decisions for RLEM in Australian broad-acre farming systems. Our analysis highlights the interplay between technical knowledge, risk attitude, and advisory influence in driving insecticide use and broader management practices. While previous work has emphasised the importance of knowledge for IPM adoption [12], our findings extend this by showing that even relatively knowledgeable advisors and growers may not translate awareness into reduced insecticide use when managing RLEM. Instead, psychological and contextual drivers, particularly risk aversion, appear to exert a stronger influence on management behaviour.

Previous research has shown that “on the ground” experience is an important factor for both grower and advisor knowledge and decision-making [37]. We found that both growers and advisors from the West had higher knowledge of RLEM than those from the East. This could be due to the fact that insecticide resistance in RLEM first evolved in Western Australia [29], and resistance issues in this species are much more prevalent in that state [30]. As a consequence, advisors and growers from the West have more experience managing resistant mite populations, with direct experience generally related to knowledge in the context of pest management [38,39]. Knowledge levels were consistently higher in advisors than in growers, particularly for insecticide resistance, but familiarity with the National RLEM Insecticide Resistance Management Strategy was low across both groups. Furthermore, a significant percentage of both growers and advisors did not know that RLEM has evolved resistance to the two chemical MoA groups (synthetic pyrethroids and organophosphates) that are most commonly being used to control this pest. As expected, knowledge increased with age and career stage, highlighting the importance of mentoring by more experienced growers and advisors in supporting those in earlier career stages [40].

Among growers, greater knowledge was only weakly associated with reduced insecticide spraying, suggesting that information alone does not strongly shift practice in the context of RLEM management. In fact, even though RLEM has evolved resistance to synthetic pyrethroids and organophosphates across large parts of western and eastern Australia [30], these remain the most frequently used insecticides against RLEM. A more striking finding was the disconnect between advisors’ self-reported adoption of an IPM mindset and their recommendations. For example, even advisors who reported they ‘Always’ or ‘Often’ employ IPM still recommended regular foliar insecticide applications to control RLEM to the majority of their grower clients. Taken together, these results suggest that IPM may function more as a general guiding philosophy than as a consistent determinant of specific management decisions for RLEM. This apparent gap between knowledge, stated attitudes, and practice is consistent with previous observations of the challenges with behavioural change in resistance management, and may reflect the influence of external factors such as client expectations, advisory business models, and risk management norms [41,42]. Addressing this disconnect will likely require extension approaches that move beyond awareness-raising, towards tools and support that help advisors and growers operationalise IPM principles for RLEM management.

Risk aversion showed a stronger and more consistent association with insecticide use than knowledge. Higher scores on the risk aversion index (RAI) were associated with an increased likelihood of both growers spraying insecticides for RLEM and advisors recommending sprays, regardless of demographic variables. Notably, growers reported being more willing to take risks in general farming decisions yet were also more concerned about economic losses from RLEM, highlighting the duality of risk attitudes in agricultural contexts. Advisors, in contrast, displayed higher overall RAI values, reflecting a stronger tendency towards precaution in giving advice and adopting new practices. However, as Pannell [40] noted, risk aversion alone is not always a reliable predictor of decision-making for insecticide use, although it can help explain certain behaviours when considered alongside other factors such as knowledge. Moreover, growers and advisors are faced with multiple, often competing risks (e.g., climatic, environmental, and economic factors) which interact and evolve over time [42]. Interestingly, growers’ RAI scores were not associated with their own reported experience of significant economic losses from RLEM in the preceding five years, suggesting that growers’ risk attitudes may be relatively stable rather than strongly reshaped by recent adverse events. In contrast, the positive relationship between advisors’ RAI scores and the proportion of their clients who had experienced significant RLEM-related losses suggests that advisors’ risk perceptions may

be influenced by cumulative exposure to client outcomes. These findings underscore the importance of considering psychosocial and professional risk contexts when designing resistance management strategies, as advisors' recommendations can reinforce risk-averse, chemical-reliant practices among their clients.

From an applied perspective, our findings suggest that effective RLEM resistance management requires interventions targeting capability, opportunity, and motivation. To build capability, training programmes should move beyond basic RLEM identification to include practical skills in resistance monitoring and IPM implementation, given the low familiarity with the National Insecticide Resistance Management Strategy. Mentoring programmes pairing experienced practitioners with early-career advisors could address the knowledge gradient observed across career stages. To create opportunity, regional demonstration sites showcasing successful non-chemical RLEM management could help close the gap between stated IPM attitudes and actual behaviours [43], while decision-support tools that explicitly account for risk perceptions may help reduce reliance on prophylactic spraying, particularly when economic risk is perceived as high [26]. Most importantly, to shift motivation, interventions should directly address risk aversion, particularly among advisors. The Theoretical Domains Framework identifies emotions, beliefs about consequences, and reinforcement as key motivational barriers [44]. In the context of RLEM management, this could include the following tactics: (1) persuasion through peer-to-peer learning, reframing IPM as risk-reducing, (2) incentivization through market-based rewards for resistance stewardship, and (3) simple methods to quantify the economic risks of spraying insecticides versus not spraying [26].

There are limitations to this study that should be acknowledged. As with all surveys, responses may be influenced by self-reporting biases, and incomplete responses reduced sample sizes in some subgroups. While the survey captured a broad geographic range, respondents were not evenly distributed between eastern and western regions. The survey design also captured practices and attitudes at a single point in time, whereas pest management behaviours and risk attitudes may shift seasonally or in response to pest outbreaks. Future work would benefit from combining longitudinal surveys with qualitative methods such as interviews or case studies to better understand the contextual drivers of decision-making. Linking survey data to observed on-farm management outcomes would also strengthen the evidence base for designing RLEM management interventions [45].

Overall, this study demonstrates that both knowledge and risk aversion play critical roles in shaping RLEM management practices, but risk aversion exerts a stronger and more consistent influence than knowledge alone. Importantly, advisors' recommendations appear to amplify risk-averse tendencies and reinforce reliance on insecticides to control RLEM, even where knowledge of resistance and IPM principles is relatively strong. Addressing these dynamics will be essential for improving adoption of resistance management strategies and prolonging the efficacy of available insecticides used for RLEM control.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/arthropoda4010002/s1>, Table S1. Demographics (age, region, industry and career stage) of growers and advisors surveyed in this study; Table S2. Knowledge index (KI) scores of growers and advisors in each demographic group; Table S3. Probability of growers spraying foliar insecticides targeting RLEM once or more per season for each demographic group; Table S4. Probability of advisors that recommend their grower clients spray insecticides to control RLEM for each demographic group; Table S5. Percentage of growers and advisors reporting how often they used or advised the use of different insecticides to control RLEM; Table S6. Percentage of growers from the East and West regions reporting how often they used different insecticides to control RLEM; Table S7. Relationship between respondents' knowledge index (KI) scores and the probability of growers spraying foliar insecticides to control RLEM once or more per season,

or advisors recommending their grower clients spray foliar insecticides to control RLEM; Table S8. Percentage of growers and advisors self-reporting their confidence levels in making RLEM management decisions; Table S9. Percentage of growers and advisors self-reporting their frequency of employing an Integrated Pest Management (IPM) mindset; Table S10. Risk aversion index (RAI) scores of growers and advisors in each demographic group; Table S11. Relationship between respondents' risk aversion index (RAI) scores and the probability of growers spraying foliar insecticides to control RLEM once or more per season, or advisors recommending their grower clients spray foliar insecticides to control RLEM; Table S12. Risk aversion index (RAI) scores of growers who reported experiencing a significant economic loss from RLEM in the past 5 years; Table S13. Relationship between advisors' risk aversion index (RAI) scores and the percentage of their grower clients that have experienced a significant economic loss from RLEM in the past 5 years; Figure S1. Percentage of growers and advisors reporting how often they used or advised the use of (a) SPs, (b) OPs, (c) neonicotinoids, (d) fiproles (fipronil), and (e) diafenthiuron to control RLEM. Lowercase letters indicate significant differences within each plot. Nev = never; Rar = rarely; Som = sometimes; Oft = often, Alw = always. There were no respondents who reported they would always use diafenthiuron. SPs = synthetic pyrethroids; OPs = organophosphates. Shaded areas represent 95% confidence intervals; Figure S2. Percentage of growers from the East and West regions reporting how often they used (a) SPs, (b) OPs, (c) neonicotinoids, (d) fiproles (fipronil), and (e) diafenthiuron to control RLEM. Lowercase letters indicate significant differences within each plot. Nev = never; Rar = Rarely; Som = sometimes; Oft = often, Alw = always. There were no respondents who reported they would always use diafenthiuron. SPs = synthetic pyrethroids; OPs = organophosphates. Shaded areas represent 95% confidence intervals; Figure S3. Percentage of growers and advisors self-reporting the factors influencing their use of insecticides to control RLEM. Numbers next to each bar represent the total number of responses selected; Figure S4. Risk Aversion Index (RAI) scores of growers and advisors by (a) age, (b) region, (c) industry, and (d) career stage. Lowercase letters indicate significant differences within each plot. For industry categories, Grains = grain crops only; M&L = meat and livestock only; Mixed = grain crops and meat and livestock. For career stage, Early = 0–5 years of experience; Mid = 6–10 years of experience; Late = >10 years of experience. Shaded areas represent 95% confidence intervals; Figure S5. Relationship between advisors' risk aversion index (RAI) scores and the percentage of their grower clients that have experienced a significant economic loss from RLEM in the past 5 years. The risk aversion index ranges from –100 to 100. Shaded areas represent 95% confidence intervals. Supplementary Materials File S1. Online survey distributed to growers and advisors in eastern and western Australian regions where RLEM occurs.

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