Pesticide Effects on Beneficial Insects and Mites in Vegetables

Dr Paul Horne
IPM Technologies Pty Ltd

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Authors: **Paul Horne, Peter Cole & Anna Cutler**

Research Provider: **IPM Technologies Pty Ltd**

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Project Leader: Dr Paul Horne
IPM Technologies Pty Ltd
PO Box 560
Hurstbridge 3099
Victoria, Australia

Ph: 03 9710 1554
Email: ipmtechnologies@bigpond.com

Personnel: Mr Peter Cole, IPM Technologies Pty Ltd
Dr Anna Cutler, IPM Technologies Pty Ltd
Dr Amanda Kobelt, Department of Primary Industries, Victoria
Ms Sarita Kulkarni, Department of Primary Industries, Victoria
Ms Kate Lorey, IPM Technologies Pty Ltd

This report describes the acute and long-term impacts that pesticide applications have on beneficial insects and mites so that pesticide compatibility with biological control in IPM programs can be improved.

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MEDIA SUMMARY

As the vegetable industry moves toward adopting more sustainable pest management practices and chemical companies manufacture more selective pesticides, growers and advisors need to know the effects of these chemicals on beneficial insects and mites, in order to maximise their preservation in crops. This project began the task of testing numerous pesticides for their impact on beneficial invertebrates. Laboratory bioassays assessed the survival and mortality of insects and mites treated with pesticides, and long-term tests investigated whether some pesticides affected reproduction in some species.

Our results showed that many of the modern selective insecticides can be useful for integrated pest management (IPM) programs because they were less harmful than the older style broad-spectrum insecticides. There was, however, much variability in the impacts of the selective insecticides on beneficial species. Generally, the selective insecticides and some fungicides caused a range of mortalities and it was not possible to predict these impacts on insects prior to testing. That is, pesticides sometimes affected closely related species differently.

This project provides to the vegetable industry essential knowledge about the effects of pesticides on key beneficial species. This information is displayed on the Ausveg website (www.ausveg.com.au) in the Grower Portal section. This project tested 24 pesticides on predatory and parasitic insects and predatory mites. However, the sheer numbers of beneficial species and pesticide combinations that need to be examined mean that this kind of pesticide testing is almost limitless. We have commenced by testing what we believe are the most urgent combinations. It is recommended that, in the future, all new pesticide registrations should require testing of the product for the impact on beneficial species so that the compatibility with IPM programs can be better ascertained.

TECHNICAL SUMMARY

As broad-spectrum insecticides become less appealing to growers, the combined pest control strategies of using selective pesticides in conjunction with beneficial insect and mite species is increasingly being adopted for Australian vegetable crops. Integrated Pest Management (IPM) programs require knowledge of how to preserve beneficial organisms, and so vastly more information is needed on how pesticides affect beneficial species than is currently available. For IPM to be successful, it is essential that pesticide applications cause minimal disruption to biological control agents.

This project rigorously tested a range of pesticides used by the vegetable industry to determine their effect on beneficial insects and mites that commonly inhabit vegetable crops in Australia. Our standard testing procedure was by laboratory bioassays that determined the acute and long-term (generational) impacts of pesticides on beneficial insects and mites. More than 300 bioassays were performed with 24 pesticides on a total of 13 insect and mite species, but not all combinations of species and pesticide were tested. The bioassays tested juveniles of predatory species and adults of parasitic species. Acute bioassays exposed specimens to pesticides by direct sprays and by contact with dried residues. Long-term tests on predatory species determined pesticide impacts over one generation by measuring survival at maturity, pre-reproductive period and fecundity.

Perhaps the most significant finding of this research is that there is high variability between the impacts of the modern selective insecticides and some fungicides on various species. Closely related beneficial species were sometimes found to be differently affected by pesticide exposure. In addition, direct spray application, exposure to residues and longer-term tests had vastly different effects for some species. The exceptions were the broad-spectrum insecticides that were harmful to virtually all species tested.

In accordance with the large variation in pesticide effects, generalisations are not possible. Our research shows that the common method of ranking chemical toxicity (eg from safest to most harmful) is too simplistic, as is grouping beneficials into types. Instead, comprehensive information is necessary to show the effects of each pesticide on relevant beneficial species. The use of different bioassay tests was found to be necessary to accurately predict the worst effects of some chemicals on beneficial species.

The main avenue of information transfer from this project to growers and advisors is via the Ausveg website[1]. This consists of a table illustrating the toxicity of each chemical tested to each species tested and additional detailed information in text. We suggest that this information be available to all interested parties, rather than just via the website Grower Portal.

The sheer breadth of combinations of beneficial species and pesticides required to be tested, and frequent appearance of new products on the market, mean that this kind of pesticide testing is almost limitless. In order to gain the most benefit from naturally occurring biological control agents we need to better understand the complex effects of selective insecticides.

[1] www.ausveg.com.au

INTRODUCTION

As the use of broad-spectrum insecticides is increasingly understood to be unsustainable, the adoption of Integrated Pest Management (IPM) continues to grow in most vegetable production industries. There is increasing awareness of the advantages of preserving and using beneficial predatory and parasitic insect and mite species for controlling pests. Successful adoption of IPM requires good knowledge of the role of beneficial species in crops and pest control methods that promote their preservation (Lewis *et al.* 1997). For instance, broad-spectrum pesticides that are commonly applied to crops are usually toxic to beneficial species that live in crop areas (Perkins 1982). Therefore, these older style pesticides are more or less incompatible with IPM programs, as they tend to destroy resident invertebrate populations. More recently developed 'selective' insecticides commonly claim to be safe to use alongside biological control agents. But exactly how safe are these products to beneficial insect and mite species?

The modern manufacture of selective pesticides has provided growers with pest management tools which are far more compatible with IPM than broad-spectrum insecticides, as they are generally more selective in their toxicity and so more closely target pests (Hainzl *et al.* 1998). Previous research and practical experience has shown that the combined use of selective chemicals with biological control agents in IPM programs can provide highly effective long-term management of pest populations (Kogan 1998; Horne & Page 2008). However, as selective pesticides do not consistently kill everything, their effects on beneficial organisms are likely to be complex and varied. For example, the selective insecticide spinosad (Success [Dow]) is lethal to only some life-stages of green lacewings and depends on whether directly sprayed or ingested (Mandour 2009). Whilst the availability of selective chemicals has made an enormous contribution to the adoption of IPM by Australian vegetable growers, their impacts on the array of beneficial species that provide biological control of pest species is not well understood.

Although there is information on pesticide effects on beneficial species in Australia, there is currently no comprehensive source of information concerning vegetable crops. There is information from research on specific crops, including: cotton (the Cotton IPM Guidelines Support Document 1[2]); brassicas (the National Diamondback Moth Project *Impact of insecticides on natural enemies found in Brassica vegetables*[3]); and grape vines (Sustainable Viticulture project *Vineyard management to maximize beneficial invertebrates to increase the bottom line*). Although the species tested represent the major beneficial species associated with these crops, there are many other beneficial insects and mites not tested which occur in other types of vegetable crops. Chemical manufacturers also provide limited information about chemical effects on beneficials, although it is rarely comprehensive. Their claims of safety to beneficials may be based on sound research data from independent researchers; however manufacturers may only show favourable results. For example, Success is claimed by Dow AgroSciences to have low toxicity to beneficial arthropods; however it is known to be harmful to *Trichogramma sp.*, some species of predatory mites and ladybirds (Williams *et al* 2003).

Claims of pesticide effects on beneficial species are often derived only from acute tests or small-plot field trials and sometimes only concerning a very few species. There are other

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[2] www. cotton.pi.csiro.au/Publicat/Pest/
[3] www.sardi.sa.gov.au/pages/ento/dbm/dbm_nat.htm:sectID=469&tempID=1

important pesticide effects such as sub-lethal impacts which include reproductive failure or behavioural changes. These effects do not show up in acute testing (Stark & Banks 2003). In other words, it is possible to slowly kill a population without any acute toxicity being observed in the first few days. In addition, although extensive pesticide testing has been carried out overseas, articles often describe the effects of single pesticides with single beneficial species, which would be laborious to sort through. Also, overseas testing is often on species that do not occur in Australia[4]. Closely related insect or mite species can be differently affected by the same pesticide, so generalisations about insect groups can not readily be made (James 2004). This lack of relevant information on local beneficial species, incomplete or false information, and insufficient testing of pesticides for sub-lethal effects means that it is impossible to assess the suitability of many pesticides within an Australian IPM strategy. It is clear that growers and their advisors need an independent source of information for determining which pesticides are safe to use in their IPM crops.

This project aims to produce an independent source of complete data on the effects of pesticides for the public domain to benefit growers and advisors wanting to implement and improve IPM on their farms. We aim to determine the acute and sub-lethal effects of pesticides on beneficial insects and mites which inhabit a range of vegetable crops. The project will allow comparison of pesticide products using a standardised test that comprises a single application at the label rate. Pesticide impacts on beneficial species could be different if multiple applications are made or if higher rates are applied.

[4] www.koppert.com

MATERIALS & METHODS

The basic method of testing pesticide toxicities and providing comparative assessment is by laboratory bioassay. Due to the complex nature of insecticide action in the field, laboratory bioassays are the most efficient way to test the impact of pesticides (e.g. compared to field trials) because the many variables can be controlled and tests can be accurately repeated for different species/pesticide combinations. Laboratory-based research also has the advantage of allowing work to be year round, and not dependent on seasonal conditions. Several beneficial species used in bioassays were cultured in the laboratory at IPM Technologies Pty Ltd. Other species were cultured in interstate insectaries and were obtained for use in bioassays, and others were collected from the field.

The following beneficial species were subjected to pesticide bioassays:

Scientific name	Common name	Beneficial group
Coccinella transversalis	Transverse ladybird	Predatory beetle
Harmonia conformis	Common-spotted ladybird	Predatory beetle
Hippodamia variegata	White-collared ladybird	Predatory beetle
Dalotia sp.	Predatory rove beetle	Predatory beetle
Micromus tasmaniae	Brown lacewing	Predatory lacewing
Nabis kinbergii	Damsel bug	Predatory bug
Melangyna viridiceps	Common Hoverfly	Predatory fly
Phytoseiulus persimilis	Persimilis	Predatory mite
Neoseiulus cucumeris	Cucumeris	Predatory mite
Aphidius colemani	General aphid parasite	Parasitoid wasp
Diadegma semiclausum	Plutella parasite	Parasitoid wasp
O*rgilus lepidus*	Potato tuber moth parasite	Parasitoid wasp
Trichogramma pretiosum	Trichogramma	Parasitoid wasp

Bioassays involved exposing beneficial species to pesticides in the laboratory using a standardised sequential testing regime. The initial two tests for each species/pesticide combination exposed specimens by direct spray application and by exposure to dried pesticide residues on treated leaf surfaces. These acute tests determined the short-term impact of the pesticide over 72 hours. In some cases where the mortality of individuals was not high (i.e. <75%), a second tier of testing was performed assessing long-term impacts. Long-term assessment was over an entire generation and measured survival to maturity, fecundity and generation time.

Acute bioassays

For the acute bioassays, first-instar juveniles of predatory insects and adults of predatory mites and parasitic wasps were either directly sprayed or exposed to dried residues of each pesticide. The directly sprayed specimens were housed after exposure in small ventilated containers and incubated at 24°C for 72 hours. A cabbage leaf disk and suitable food source were provided to specimens. For the dried residue bioassays, the cabbage leaf disk was sprayed to the point of run-off and air dried for two hours prior to placement with insect or mite specimens in ventilated containers. In general, ten repeats of each treatment were carried out. Alongside every chemical treatment bioassay a control was concurrently run, in which specimens or cabbage leaf disks were exposed to water. For all bioassays, control and treatment groups were compared and data were statistically analysed to determine the percentage mortality observed for each treatment and to separate differences between treatment means at the 5% level of significance.

Pesticides were selected for tests depending on at least one of several factors:

1. Products that are in common use in the vegetable industry.
2. Claims by their manufacturer that they are suitable for IPM crops.
3. Products that appear to be safe to some beneficial species and harmful to other species.
4. New products and pesticides for which new APVMA permits are granted.

The following insecticides, fungicides and herbicides were tested:

Trade name	Manufacturer	Active ingredient	Product Concentration
Insecticides			
Avatar®	Dupont	indoxacarb 400 g/L	0.25 g/L
Belt®	Bayer	flubendiamide 480 g/L	0.2 mL/L
Chess®	Syngenta	pymetrozine 500 g/kg	0.4 g/L
Confidor 200SC®	Bayer	imidacloprid 200 g/L	0.25 mL/L
Coragen®	Dupont	chlorantraniliprole 200 g/L	0.2 mL/L
Cypermethrin®	Halley	cypermethrin 200 g/L	0.2 mL/L
Dipel®	Sumitomo	*Bacillus thuringiensis* toxin	1.0 g/L
Karate®	Syngenta	lambda-cyhalothrin 250 g/L	0.048 mL/L
Lorsban 500EC®	Dow Ag. Sc.	chlorpyrifos 500 g/L	1.5 mL/L
Movento®	Bayer	spirotetramat 240 g/L	0.4 mL/L
Pirimor®	Syngenta	pirimicarb 500 g/kg	2.0 g/L
Proclaim®	Syngenta	emamectin benzoate 44 g/kg	0.5 g/L
Regent 200SC®	Nufarm	fipronil 200 g/L	0.5 mL/L
Success®	Dow Ag. Sc.	spinosad 120 g/L	0.4 mL/L
Vertimec®	Syngenta	abamectin 18 g/L	0.6 mL/L
Fungicides			
Amistar®	Syngenta	azoxystrobin 250 g/L	0.8 mL/L
Barrack®	Crop Care	chlorothalonil 720 g/L	4.6 g/L
Filan®	Nufarm	boscalid 500 g/kg	2.0 g/L
Norshield WG®	Nipro	cuprous oxide 750 g/kg	1.05 g/L
Penncozeb DF®	Nufarm	mancozeb 750 g/kg	2.0 mL/L
Polyram®	Nufarm	metiram 700 g/kg	2.0 g/L
Rebound®	Kiwi Rural T.	propineb 550 g/kg + oxadixyl 80 g/kg	2.5 g/L
Thiovit®	Syngenta	elemental sulphur 800 g/kg	2.0 g/L
Herbicides			
Select®	Sumitomo	clethodim 240 g/L	2.5 mL/L

Sub-lethal / long-term bioassays

The second tier of bioassays was performed when acute mortality was not high and determined the effect of pesticides on species over one generation. Due to the length of time required for these tests, priority was given to the most relevant combinations of pesticide and beneficial species.

Treatment application was the same as for the direct application acute bioassays, except that 40 first-instar individuals were sprayed. The treated juveniles were distributed in three ventilated polypropylene containers (27x19x8cm) of 13-14 individuals and were reared through to adults at 24°C. The adults remained in the containers for five days after emergence and were then separated into male-female pairs in 400ml ventilated plastic containers. In addition to food sources, suitable egg-laying strata were provided.

The following observations were recorded during the life of the adult pairs: survival at maturity, pre-reproductive period (egg-hatch to first egg-lay) and fecundity (measured as number of juveniles produced). Statistical analysis separated differences between treatment means at the 5% level of significance.

For both acute bioassays and long-term bioassays, results are presented in table format for each species. All mortalities are adjusted for control mortality (Abbott 1925). Additionally, colour-coded summary tables show pesticide impacts by ranking into green ‘low harm’ (< 25% mortality), orange ‘moderately harmful’ (25-75% mortality) and red ‘harmful’ (> 75% mortality).

RESULTS

During the course of this project, more than 300 bioassays were performed. Numerous bioassays were also repeated in order to confirm initial results and to improve the accuracy of the data. A total of 24 pesticides were tested on 13 insect and mite species (see summarised results in Tables 1-3 and detailed results in Tables 4-19). Several of the most relevant combinations of insecticide/ beneficial species were subjected to both acute and fecundity bioassays. However, due to the large number of tests of interest, many combinations have only yet been tested at the acute level.

A number of broad-spectrum insecticides were tested and, not surprisingly, they invariably caused high mortality of beneficial species. For instance, Lorsban (chlorpyrifos) and Karate (lambda-cyhalothrin) caused 100% mortality in all species tested, regardless of the method of exposure. Although not quite as toxic, the broad-spectrum insecticide Regent (fipronil) caused moderate to high mortality in all species tested except *Dalotia* beetles, which suffered only 16% mortality in the residue bioassay (Table 10). Although not considered to be a broad-spectrum insecticide, the foliar rate of Confidor (imidacloprid) was highly toxic to all species except brown lacewings (20% mortality) and *Dalotia* beetles (30%).

More interesting and currently important results were gained from bioassays testing the more 'modern' selective insecticides. Most of these insecticides caused highly variable levels of mortality across different beneficial species. In fact, the only insecticide that was harmless to all species in all acute tests was Dipel, the *Bacillus thuringiensis* toxin insecticide for Lepidoptera larvae. All other selective insecticides caused some mortality to some species but not to others. Three selective insecticides commonly used in IPM for Lepidoptera pests (i.e. caterpillars) are Avatar (indoxacarb), Proclaim (emamectin benzoate) and Success (spinosad). These three insecticides caused highly variable mortalities to beneficial species in acute bioassays. For example, Avatar was lethal to ladybirds (77-96% mortality) but harmless to brown lacewings and *Trichogramma* wasps. Similarly, Proclaim was lethal to damsel bugs (100%) and *Trichogramma* (100%) but only caused low mortality to ladybirds (<16%) and brown lacewings (24%). Success was found to be lethal to *Trichogramma* (97-99%) and hoverflies (100%) but mostly harmless to other species tested. New products released during the life of this project were also tested. Acute tests showed that Belt (flubendiamide), Coragen (chlorantraniliprole) and Movento (spirotetramat) were all harmless to brown lacewings, transverse ladybirds and damsel bugs. However, fecundity bioassays need to be completed to confirm their safety to populations of these species.

In addition to causing varying levels of mortality in different species, several selective insecticides were harmful only by a particular method of exposure. That is, an insecticide was not harmful when sprayed directly onto specimens, but was lethal as a residue. For example, Avatar caused low mortality to the three species of ladybird tested by direct spray application (0% 2.6% 10%), but caused high mortality when the same ladybird species were exposed to dried residues (80% 77% 96%) (Tables 5, 6 and 7). Similarly, Success was harmless by direct application to brown lacewings (0%) but residues caused moderate mortality (39%) (Table 4). This kind of result was quite common, but rarely with direct application being more harmful than residues.

In addition to different modes of exposure, the length of the bioassay uncovered different results. That is, longer-term fecundity bioassays sometimes revealed negative impacts on species that did not show up in acute tests. For example, although Pirimor (pirimicarb) caused very low mortality (8%) to damsel bugs when directly applied, it significantly reduced the number of eggs laid by females (Table 19). Further, although Confidor caused low mortality (20%) to lacewings in acute tests, it significantly reduced survival of individuals to maturity (Table 17). Similarly, Chess (pymetrozine) was harmless to transverse ladybirds in acute tests (6.7%), but caused almost all individuals to die before they could mature into adults (Table 18).

Trichogramma wasps were generally more sensitive to insecticides than other species. Almost all of the pesticides tested on *Trichogramma* caused significantly higher mortalities than the corresponding controls (Table 11). Nevertheless, some methods of exposure were not harmful and many of the mortalities were not high (<75%). For other beneficial species the selective pesticides caused variable mortalities and there were no clear patterns of toxicity. That is, it was not possible to predict the effect of a particular pesticide on a certain species, based on its effect on other species. Some results were different, even for closely related species. For example, Chess was moderately harmful to the white-collared ladybird in acute tests (48%) but harmless to transverse (6.7%) and common-spotted ladybirds (0%).

In addition to insecticides, which may be expected to impact negatively on non-target invertebrates, other pesticides such as fungicides and herbicides were also found to negatively affect beneficial species (Tables 2 and 3). Most of the fungicides tested in this project were harmless by acute and long-term toxicity, however there were some exceptions. Barrack (chlorothalonil) caused moderate mortality to the common spotted ladybird (40%). Also, Polyram (metiram) was safe to brown lacewings (<2.5%) and ladybirds (<3.7%), but exposure to residues was lethal to *Trichogramma* wasps (85%). The only herbicide tested, Select (clethodim) was harmless by direct spray application to transverse ladybirds (10%) but toxic by residue exposure (80%).

Table 1. Summary impact of insecticides on beneficial species

Product / Insecticide & active	Direct spray application										
Avatar indoxacarb	Mt	Hc	Hv	Ct	Nk	Da	Tp				
	FEC			FEC	FEC						
Belt flubendiamide	Mt	Ct	Nk	Ds	Tp						
Chess pymetrozine	Mt	Hc	Hv	Ct	Nk	Mv	Da	Ac	Ol	Ds	Tp
	FEC			FEC	FEC						
Confidor imidacloprid	Mt	Hc	Hv	Ct	Nk	Tp	Da				
	FEC										
Coragen chlorantraniliprole	Mt	Ct	Nk	Ds	Tp						
Cypermethrin cypermethrin	Mt	Ct	Nk	Pp							
Dipel *B. thuringiensis*	Mt	Ct	Nk	Hv	Hc	Pp	Ol				

Product / Insecticide & active	Dried residues exposure										
Avatar indoxacarb	Mt	Hc	Hv	Ct	Nk	Tp					
Belt flubendiamide	Mt	Ct	Nk	Tp							
Chess pymetrozine	Mt	Hc	Hv	Ct	Nk	Da	Ac	Tp			
Confidor imidacloprid	Mt	Hc	Hv	Ct	Nk	Tp	Da				
Coragen chlorantraniliprole	Mt	Ct	Ds	Tp							
Cypermethrin cypermethrin	Mt	Ct	Nk								
Dipel *B. thuringiensis*	Mt	Ct	Nk	Hv	Hc	Ol					

KEY **Low** **Moderately harmful** **Harmful** **FEC = fecundity test**

Species tested

Ac	*Aphidius colemani*	Parasitoid wasp of aphids	Mt	*Micromus tasmaniae*	Brown lacewing
Ct	*Coccinella transversalis*	Transverse ladybird	Mv	*Melangyna viridiceps*	Hoverfly
Da	*Dalotia sp.*	Ground-dwelling predatory beetle	Nk	*Nabis kinbergii*	Damsel bug
Ds	*Diadegma semiclausum*	Parasitoid wasp of *Plutella*	Ol	*Orgilus lepidus*	Parasitoid wasp of potato moth
Hc	*Harmonia conformis*	Common-spotted ladybird	Pp	*Phytoseiulus persimilis*	Predatory mite
Hv	*Hippodamia variegata*	White-collared ladybird	Tp	*Trichogramma pretiosum*	Parasitoid wasp of Lepid. eggs

Table 1 (cont.)

Product / Insecticide & active	Direct spray application												Dried residues exposure										
Karate lambda-cyhalothrin	Mt	Hv											Mt	Hv									
Lorsban chlorpyrifos	Mt	Hv	Hc	Ct	Nk	Tp	Da	Pp					Mt	Hv	Hc	Tp	Da						
Movento spirotetramat	Mt	Ct	Nk	Tp									Mt	Ct	Nk	Tp							
Pirimor pirimicarb	Mt	Hc	Hv	Ct	Nk	Tp	Da	Mv	Ol				Mt	Hc	Hv	Ct	Nk	Tp					
	FEC			FEC	FEC																		
Proclaim emamectin benzoate	Mt	Hc	Hv	Ct	Nk	Da	Tp	Mv	Nc	Pp			Mt	Hc	Hv	Ct	Nk	Da	Tp	Nc			
	FEC			FEC				FEC															
Regent 200SC fipronil	Mt	Hc	Hv	Nk	Tp	Da							Mt	Hv	Nk	Da							
Success spinosad	Mt	Hc	Hv	Ct	Nk	Mv	Tp						Mt	Ct	Nk								
	FEC			FEC	FEC																		
Vertimec abamectin	Mt	Ct	Nk	Tp	Pp								Mt	Ct	Nk	Pp							

KEY **Low** **Moderately harmful** **Harmful** **FEC = fecundity test**

Species tested

Ct	*Coccinella transversalis*	Transverse ladybird	Nc	*Neoseiulus cucumeris*	Predatory mite
Da	*Dalotia sp.*	Ground-dwelling predatory beetle	Nk	*Nabis kinbergii*	Damsel bug
Hc	*Harmonia conformis*	Common-spotted ladybird	Ol	*Orgilus lepidus*	Parasitoid wasp of potato moth
Hv	*Hippodamia variegata*	White-collared ladybird	Pp	*Phytoseiulus persimilis*	Predatory mite
Mt	*Micromus tasmaniae*	Brown lacewing	Tp	*Trichogramma pretiosum*	Parasitoid wasp of Lepid. eggs
Mv	*Melangyna viridiceps*	Hoverfly			

Table 2. Summary impact of fungicides on beneficial species

Product / Fungicide & active	Direct spray application					Dried residues exposure			
Amistar azoxystrobin	Ct								
Barrack chlorothalonil	Mt	Hc	Ct	Nk	Tp	Mt	Ct	Nk	Tp
				FEC					
Filan boscalid	Mt	Hc	Ct	Nk		Mt	Nk		
			FEC						
Mankocide Copper hydroxide + mancozeb	Tp					Tp			
Norshield WG cuprous oxide	Mt	Hc	Nk	Tp	Da	Mt	Tp		
Penncozeb DF mancozeb	Ct	Nk	Tp			Ct	Tp		
Polyram metiram	Mt	Hc	Nk	Tp		Mt	Tp		
Rebound WP propineb oxadixyl	Mt	Ct	Nk	Tp		Mt	Tp		
		FEC							
Thiovit elemental sulphur	Mt	Ct	Hv	Nk		Mt			

KEY **Low** **Moderately harmful** **Harmful** FEC = **fecundity test**

Species tested

Ct	*C. transversalis*	Transverse ladybird	Hv	*H. variegata*	White-collared ladybird	Tp	*T. pretiosum*	Parasitoid wasp
Da	*Dalotia sp.*	Predatory beetle	Mt	*Micromus tasmaniae*	Brown lacewing			
Hc	*H. conformis*	Common-spotted ladybird	Nk	*Nabis kinbergii*	Damsel bug			

Table 3. Summary impact of herbicides on beneficial species

Product Herbicide & active	Direct spray application											Dried residues exposure										
Select clethodim	Ct	Nk										Ct										
	FEC																					

KEY **Low** **Moderately harmful** **Harmful** **FEC = fecundity test**

Species tested

Ct *Coccinella transversalis* Transverse ladybird

Nk *Nabis kinbergii* Damsel bug

Acute Bioassays

Table 4. Effects of pesticides on *Micromus tasmaniae* (Brown lacewing)

Product	Active ingredient	Product conc. (g or mL/L)	Mortality* (%)	
			Direct application	Dried residues
Insecticides				
Avatar	indoxacarb	0.25	3.3	4.5
Belt	flubendiamide	0.2	7.2	0
Chess	pymetrozine	0.4	0	0
Confidor	imidacloprid	0.25	20*	3.3
Coragen	chlorantraniliprole	0.2	0	6.7
Cypermethrin	cypermethrin	0.2	83*	47*
Dipel	*B. thuringiensis* toxin	1.0	0	0
Karate	lambda cyhalothrin	0.048	100*	100*
Lorsban 500EC	chlorpyrifos	1.5	100*	100*
Movento	spirotetramat	0.4	0	3.5
Pirimor	pirimicarb	2.0	3.3	12.5
Proclaim	emamectin benzoate	0.5	24*	9.8
Regent 200SC	fipronil	0.5	100*	95*
Success	spinosad	0.4	0	39*
Vertimec	abamectin	0.6	0	6.7
Fungicides				
Amistar	azoxystrobin	0.8		
Barrack	chlorothalonil	4.6	0	8.0
Filan	boscalid	2.0	13.9	0
Norshield WG	cuprous oxide	1.05	0	0
Polyram	metiram	2.0	2.5	0
Rebound WP	propineb + oxadixyl	2.5	0	0
Thiovit	elemental sulphur	2.0	0	0

* Mortality is significantly greater than control mortality (P<0.05).

Table 5. Effects of pesticides on *Coccinella transversalis* (Transverse ladybird)

Product	Active ingredient	Product conc. (g or mL/L)	Mortality* (%)	
			Direct application	Dried residues
Insecticides				
Avatar	indoxacarb	0.25	0	80*
Belt	flubendiamide	0.2	3.3	0
Chess	pymetrozine	0.4	6.7	20*
Confidor	imidacloprid	0.25	100*	100*
Coragen	chlorantraniliprole	0.2	0	0
Cypermethrin	cypermethrin	0.2	100*	100*
Dipel	*B. thuringiensis* toxin	1.0	10	0
Lorsban 500EC	chlorpyrifos	1.5	100*	100*
Movento	spirotetramat	0.4	0	0
Pirimor	pirimicarb	2.0	13	7.4
Proclaim	emamectin benzoate	0.5	0	7.1
Success	spinosad	0.4	7.8	0
Vertimec	abamectin	0.6	97*	59*
Fungicides				
Amistar	azoxystrobin	0.8	0	
Barrack	chlorothalonil	4.6	0	0
Filan	boscalid	2.0	10	
Norshield WG	cuprous oxide	1.05	1.3	10
Penncozeb DF	mancozeb	2.0	4.0	9.5
Polyram	metiram	2.0	3.7	0
Rebound WP	propineb + oxadixyl	2.5	0	0
Thiovit	elemental sulphur	2.0	0	
Herbicides				
Select	clethodim	2.5	10	80*

* Mortality is significantly greater than control mortality ($P<0.05$).

Table 6. Effects of pesticides on *Hippodamia variegata* (White-collared ladybird)

Product	Active ingredient	Product conc. (g or mL/L)	Mortality* (%)	
			Direct application	Dried residues
Insecticides				
Avatar	indoxacarb	0.25	2.6	77*
Confidor	imidacloprid	0.25	97*	100*
Chess	pymetrozine	0.4	48*	28*
Dipel	*B. thuringiensis* toxin	1.0	0	0
Karate	lambda cyhalothrin	0.048	100*	100*
Lorsban 500EC	chlorpyrifos	1.5	100*	100*
Pirimor	pirimicarb	2.0	17*	12
Proclaim	emamectin benzoate	0.5	0	10
Regent 200SC	fipronil	0.5	43*	88*
Success	spinosad	0.4	6.0	
Fungicides				
Thiovit	elemental sulphur	2.0	8.0	12

Table 7. Effects of pesticides on *Harmonia conformis* (Common-spotted ladybird)

Product	Active ingredient	Product conc. (g or mL/L)	Mortality* (%)	
			Direct application	Dried residues
Insecticides				
Avatar	indoxacarb	0.25	10	96*
Chess	pymetrozine	0.4	0	25*
Confidor	imidacloprid	0.25	97*	100*
Dipel	*B. thuringiensis* toxin	1.0	0	0
Lorsban 500EC	chlorpyrifos	1.5	100*	100*
Pirimor	pirimicarb	2.0	57*	
Proclaim	emamectin benzoate	0.5	13	16
Regent 200SC	fipronil	0.5	83*	
Success	spinosad	0.4	8.0	
Fungicides				
Barrack	chlorothalonil	4.6	40*	
Filan	boscalid	2.0	0	
Norshield WG	cuprous oxide	1.05	23	
Polyram	metiram	2.0	0	

* Mortality is significantly greater than control mortality ($P<0.05$).

Table 8. Effects of pesticides on *Nabis kinbergii* (Damsel bug)

Product	Active ingredient	Product conc. (g or mL/L)	Mortality* (%)	
			Direct application	Dried residues
Insecticides				
Avatar	indoxacarb	0.25	6.9	71*
Belt	flubendiamide	0.2	9.0	18
Chess	pymetrozine	0.4	4.7	14
Confidor	imidacloprid	0.25	100*	100*
Coragen	chlorantraniliprole	0.2	14	18
Dipel	*B. thuringiensis* toxin	1.0	3.0	0
Lorsban 500EC	chlorpyrifos	1.5	100*	100*
Movento	spirotetramat	0.4	0	6.7
Pirimor	pirimicarb	2.0	8.6	65*
Proclaim	emamectin benzoate	0.5	100*	97.4*
Regent 200SC	fipronil	0.5	100*	100*
Success	spinosad	0.4	0	0
Vertimec	abamectin	0.6	57*	80*
Fungicides				
Barrack	chlorothalonil	4.6	5.6	
Rebound WP	propineb + oxadixyl	2.5	3.3	
Herbicides				
Select	clethodim	2.5	7.0	

* Mortality is significantly greater than control mortality ($P<0.05$).

Table 9. Effects of pesticides on *Melangyna viridiceps* (Hoverfly)

Product	Active ingredient	Product conc. (g or mL/L)	Mortality* (%)	
			Direct application	Dried residues
Insecticides				
Chess	pymetrozine	0.4	0	
Pirimor	pirimicarb	2.0	20	
Proclaim	emamectin benzoate	0.5	27*	
Success	spinosad	0.4	100*	

Table 10. Effects of pesticides on *Dalotia sp.* (Predatory ground-dwelling beetle)

Product	Active ingredient	Product conc. (g or mL/L)	Mortality* (%)	
			Direct application	Dried residues
Insecticides				
Avatar	indoxacarb	0.25	0	0
Chess	pymetrozine	0.4	0	14
Confidor	imidacloprid	0.25	30*	0
Lorsban 500EC	chlorpyrifos	1.5	100*	100*
Pirimor	pirimicarb	2.0	1.7	
Proclaim	emamectin benzoate	0.5	24*	39*
Regent 200SC	fipronil	0.5	100*	16
Fungicides				
Norshield WG	cuprous oxide	1.05	2.4	

* Mortality is significantly greater than control mortality (P<0.05).

Table 11. Effects of pesticides on *Trichogramma pretiosum* (Parasitoid of lepidopteran eggs)

Product	Active ingredient	Product conc. (g or mL/L)	Mortality* (%)	
			Direct application	Dried residues
Insecticides				
Avatar	indoxacarb	0.25	8.6	2.5
Belt	flubendiamide	0.2	0	12.7
Chess	pymetrozine	0.4	0	57*
Confidor	imidacloprid	0.25	100*	46*
Coragen	chlorantraniliprole	0.2	51*	5.5
Lorsban 500EC	chlorpyrifos	1.5	100*	100*
Movento	spirotetramat	0.4	52*	0
Pirimor	pirimicarb	2.0	29*	100*
Proclaim	emamectin benzoate	0.5	100*	100*
Regent 200SC	fipronil	0.5	100*	
Success	spinosad	0.4	99*	97*
Vertimec	abamectin	0.6	83*	100*
Fungicides				
Barrack	chlorothalonil	4.6	0	43*
Mankocide	copper hydroxide	2.0	42*	3.6
Norshield WG	cuprous oxide	1.05	16*	2.5
Penncozeb DF	mancozeb	2.0	0	0
Polyram	metiram	2.0	48*	85*
Rebound WP	propineb + oxadixyl	2.5	15	5.2

* Mortality is significantly greater than control mortality (P<0.05).

Table 12. Effects of pesticides on *Diadegma semiclausum* (Parasitoid of Lepidoptera)

Product	Active ingredient	Product conc. (g or mL/L)	Mortality* (%)	
			Direct application	Dried residues
Insecticides				
Belt	flubendiamide	0.2	0	
Chess	pymetrozine	0.4	0	
Coragen	chlorantraniliprole	0.2	0	20

Table 13. Effect of pesticides on *Orgilus lepidus* (Parasitoid of potato tuber moth)

Product	Active ingredient	Product conc. (g or mL/L)	Mortality* (%)	
			Direct application	Dried residues
Insecticides				
Chess	pymetrozine	0.4	16	
Dipel	*B. thuringiensis* toxin	1.0	3.3	0
Pirimor	pirimicarb	2.0	58*	

Table 14. Effects of pesticides on *Aphidius colemani* (Parasitoid of aphids)

Product	Active ingredient	Product conc. (g or mL/L)	Mortality* (%)	
			Direct application	Dried residues
Insecticides				
Chess	pymetrozine	0.4	0	

Table 15. Effects of pesticides on *Neoseiulus cucumeris* (Predatory mite)

Product	Active ingredient	Product conc. (g or mL/L)	Mortality* (%)	
			Direct application	Dried residues
Insecticides				
Proclaim	emamectin benzoate	0.5	44*	47*

Table 16. Effects of pesticides on *Phytoseiulus persimilis* (Predatory mite)

Product	Active ingredient	Product conc. (g or mL/L)	Mortality* (%)	
			Direct application	Dried residues
Insecticides				
Cypermethrin	cypermethrin	0.2	100*	
Dipel	*B. thuringiensis* toxin	1.0	0	
Lorsban	chlorpyrifos	1.5	100*	
Proclaim	emamectin benzoate	0.5	98*	
Vertimec	abamectin	0.6	100*	78*

* Mortality is significantly greater than control mortality ($P<0.05$).

Sub-lethal / long-term bioassays

Table 17. Long-term effects of pesticides on *Micromus tasmaniae* (Brown lacewing)

Product	**Active ingredient**	**Survival at maturity (%)***	**Pre-reproductive period (days)***	**Fecundity (no. live offspring / female)***
Control		60	25.0	345
Insecticides				
Avatar	indoxacarb	35*	23.5	213
Chess	pymetrozine	57	22.6	250
Confidor	imidacloprid	27*	23.0	186
Pirimor	pirimicarb	65	28.2	318
Proclaim	emamectin benzoate	48	23.6	238
Success	spinosad	57	24.5	441

* Numbers in the same column are significantly different to corresponding control value (P<0.05).

Table 18. Long-term effects of pesticides on *Coccinella transversalis* (Transverse ladybird)

Product	**Active ingredient**	**Survival at maturity (%)***	**Pre-reproductive period (days)***	**Fecundity (no. live offspring / female)***
Control		79	29.8	171
Insecticides				
Avatar	indoxacarb	43*	31.8	191
Chess	pymetrozine	2.4*	-	0*
Pirimor	pirimicarb	76	46.8*	107*
Proclaim	emamectin benzoate	86	29.7	108
Success	spinosad	91	26.4	150
Fungicides				
Filan	boscalid	69	34.4	118
Rebound	propineb + oxadixyl	72	35.3	135
Herbicides				
Select	clethodim	67	27.8	165

* Numbers in the same column are significantly different to corresponding control value (P<0.05).

Table 19. Long-term effects of pesticides on *Nabis kinbergii* (Damsel bug)

Product	Active ingredient	Survival at maturity (%)*	Pre-reproductive period (days)*	Fecundity (no. live offspring / female)*
Control		38	26.0	97
Insecticides				
Avatar	indoxacarb	38	30.0	100
Chess	pymetrozine	53	26.3	117
Pirimor	pirimicarb	33	28.8	63*
Success	spinosad	37	24.5	113
Fungicides				
Barrack	chlorothalonil	44	38.2*	64

* Numbers in the same column are significantly different to corresponding control value (P<0.05).

DISCUSSION

Over the course of this project, many combinations of chemical pesticide and beneficial species were tested. Not surprisingly, broad-spectrum insecticides largely caused high mortality of beneficial species. The only insecticide that was completely harmless to all species in all tests was Dipel, the *Bacillus thuringiensis* (Bt) toxin insecticide for Lepidoptera larvae. In contrast, selective insecticides caused highly variable levels of mortality across different beneficial species. This included selective insecticides currently used in IPM programs. For example, the selective insecticide Avatar was lethal to ladybirds but not brown lacewings, Proclaim was lethal to damsel bugs but not ladybirds, and Success was lethal to Trichogramma but not other beneficial species. The consequence of these kinds of variable toxicities is that decision-making about pesticide application requires close examination of conditions, including exactly which beneficial species are present in the crop and individual effects of each chemical.

One of the differences observed in chemical action was between direct exposure and residual effects on beneficial species. Several selective insecticides were harmful to some species as a residue, but not when directly applied. For example, Avatar was harmless to the three species of ladybirds tested by direct spray application but it caused high mortality when ladybirds were exposed to dried residues. Similarly, Success was harmless by direct application to brown lacewings but residues caused moderate mortality. Only rarely was direct exposure more harmful than exposure to residues. The implications of this are that the residual effects of many insecticides may be, in fact, worse than initial sprays. However, in the residue bioassay technique there is no degradation of pesticide residues by environmental factors such as sunlight and rainfall. Therefore, pesticide residues from field applications may degrade more rapidly than residues in these bioassays and thus be less harmful to beneficial species. The degradation of pesticides may vary between products and therefore some pesticides may become less harmful to beneficial species more rapidly than others.

In addition to the acute effects of pesticides on beneficial species, longer-term observation of exposed specimens uncovered negative impacts not seen in the first 72 hours. For example, although Chess was harmless by acute toxicity to the majority of species tested, it killed almost all transverse ladybirds before they could mature into adults. Another selective insecticide that caused reduced reproduction despite appearing harmless in acute tests was Confidor applied to brown lacewings. The implications of these longer-term negative effects are that population growth of these beneficial species may be reduced or go into decline. In extreme cases, these effects may cause complete failure of a local population of a beneficial species within one generation. Similarly, other researchers have observed sub-lethal and long-term negative impacts of pesticides on beneficial insects (Forbes & Calow 2002; Stapel *et al* 2000; Walthall & Stark 1997). The repercussions of these kinds of effects in the field, particularly where ongoing IPM is being utilised, is great enough to warrant the necessity of these longer testing methods.

The long-term effects of pesticides on beneficials can broadly impact on either long-term mortality or reproduction. Stark *et al* (2007) describe how various combinations of these effects might influence the survival of the whole population in a treated crop. Whilst this study has shown that some pesticides affect reproductive success, it is beyond the scope of the project to determine the actual pathways of those effects. Whether the causes are physiological or behavioural, the important information for end-users, such as growers and IPM advisors, is simply whether or not there is an effect.

Over the course of this project, several closely related species were tested, for instance three ladybird species. This may seem unnecessary, as groups of similar species may be expected to respond in comparable ways to specific pesticides. However, this is not the case. Closely related beneficial species were found here to have different mortality levels caused by the same pesticide. For example, Chess was moderately harmful in acute tests to the white-collared ladybird but completely harmless in the same tests to transverse and common-spotted ladybirds. For many beneficial species, selective pesticides caused variable mortalities and there were no clear patterns of toxicity. That is, it was not possible to predict the effect of a particular pesticide on a certain species, based on its effect on other species. This diversity of responses to selective insecticides requires that every species needs to be tested against every pesticide in order to acquire accurate results.

Overall, the newer generation of selective insecticides are more difficult to understand than broad-spectrum insecticides, which tend to kill all invertebrates. The bioassays performed in this project have indicated that their selectivity is unpredictable and requires species-specific and detailed evaluation at different time scales in order for them to be used most effectively in IPM programs. Some selective insecticides released during the course of this project were found here not to be lethal by short-term toxicity to several beneficial species. Our acute tests showed that Belt, Coragen and Movento are all harmless to brown lacewings, transverse ladybirds and damsel bugs. These results are promising for the Australian vegetable industry, but further assessment needs to be made of longer-term effects to ascertain the true benefit that these new products can impart on IPM crops.

In general, selective insecticides can be a fantastic tool for IPM practitioners; however they must not be thought of as ‘safe’ across the board, or used haphazardly, in case they cause unexpected outcomes. Indeed, despite claims of safety to beneficial species, single applications of many selective insecticides were found here to be of a moderate or high toxicity to some beneficial species, and thus should be used cautiously. Multiple applications in the field could possibly have greater negative effects on populations than revealed in these bioassays.

The requirements for this kind of information in IPM programs is almost limitless, as new products are regularly introduced to the market, along with their claims of being suitable for IPM and ‘safe’ to beneficial species. In addition, new permits regularly grant use of pesticides in new crops, and new pest issues influence pesticide use habits. These situations mean that the need for pesticide testing on beneficial species is ongoing.

These results add significantly to the body of knowledge growers and advisors can use to carry out successful IPM programs. However we have only scratched the surface of potential testing and further chemical/species combinations need to be tested for acute and long-term effects. In addition, we have largely tested a discrete age class of specimens, that is, young juveniles. Although using vulnerable juveniles may indicate the worst case scenario, testing on other life stages – such as adults, eggs or pupae – can further illustrate the overall impact of selective pesticides (James 2004). Also, although only insecticides are intended to target invertebrates, numerous fungicides and herbicides also need to be tested for toxicity to beneficial species, as they were found here to cause negative effects on beneficial species. Further, behavioural changes caused by exposure to chemicals, such as migration from sprayed areas, may also be important indicators of pesticide effects (Desneux et al 2007). Clearly, this area of research is complex and challenging in its breadth. However, this is also an exciting time of transformation in pest control practices. These industry-wide aspirations to utilise new products to improve the sustainability and success of pest control measures is a goal well worth working towards.

TECHNOLOGY TRANSFER

The target audience for the information obtained during this project includes IPM advisors, growers using IPM and chemical resellers. The outputs of the project are relevant to the industry nationally because beneficial species from all growing regions were tested.

The primary method of information transfer is by publication on the Ausveg website (www.ausveg.com.au). For access, enter the Grower Portal and click on the 'IPM' tab, then 'Current Issues and Priorities'. The information is under the 'Guide to effects of pesticides on beneficial insects and mites' heading. We suggest that this is changed to be more accessible.

Online information has the advantage of being regularly updated and accessible to a wide audience. Primarily, the site describes pesticide effects on beneficial species for each species/pesticide combination. The text includes colour coding to give rapid information about toxicity levels.

The pesticide impact on each species is shown for up to three factors:

- Effect of wet spray contact of pesticide
- Effect of exposure to dried pesticide residues
- Effect of pesticide long-term mortality and reproduction

Summary tables of pesticide effects are included in this report and will be uploaded to the website (Tables 20a and 20b). These tables combine the data for each combination of pesticide and species into one overall rating that is easy to understand. The tables are intended to be a useful guide to pesticide effects for industry personnel who don't need or want to know the finer details of particular pesticide-species interactions. Importantly, the table retains information for each beneficial species because it is clear that even closely related species can respond differently to pesticide exposure.

In other areas of technology transfer, a scientific paper has been submitted to the Australian Journal of Entomology, titled "Acute and long-term effects of selective insecticides on *Micromus tasmaniae* Walker (Neuroptera: Hemerobiidae), *Coccinella transversalis* F. (Coleoptera: Coccinellidae) and *Nabis kinbergii* Reuter (Hemiptera: Miridae)." The paper describes the variable impacts of seven insecticides and shows the need for long-term tests in addition to acute bioassays.

An article was published in Good Fruit and Vegetables about the project, titled "Project hones in on IPM information", Good Fruit and Vegetables, September 2007, p73.

Project information has also been used in other current projects which involve demonstration of IPM (Projects VG05007 and VG06088).

Table 20a. Insecticides effects on beneficial insects and mites

Insecticide Product & active ingredient	Beneficial species												
	Brown lacewing	Transverse ladybird	Variegated ladybird	Common spotted ladybird	Damsel bug	Hoverfly	Dalotia predatory beetle	Tricho-gramma parasitoid wasp	Diadegma parasitoid wasp	Orgilus parasitoid wasp	Aphidius colemani parasitoid wasp	Persimilis predatory mite	Cucumeris predatory mite
Avatar indoxacarb													
Belt flubendiamide													
Chess pymetrozine													
Confidor imidacloprid													
Coragen chlorantraniliprole													
Cypermethrin cypermethrin													
Dipel *B. thuringiensis*													
Karate lambda-cyhalothrin													
Lorsban chlorpyrifos													
Movento spirotetramat													
Pirimor pirimicarb													
Proclaim emamectin benzoate													
Regent 200SC fipronil													
Success spinosad													
Vertimec abamectin													

Table 20b. Fungicides and herbicide effects on beneficial insects

Fungicide Product & active ingredient	**Beneficial species**						
	Brown lacewing	Transverse ladybird	Variegated ladybird	Common spotted ladybird	Damsel bug	Dalotia predatory beetle	Tricho-gramma parasitoid wasp
Amistar azoxystrobin		Low					
Barrack chlorothalonil	Low	Low		Moderately harmful	Moderately harmful		Moderately harmful
Filan boscalid	Low	Low		Low	Low		
Mankocide copper hydroxide							Moderately harmful
Norshield WG Cuprous oxide	Low			Low	Low	Low	Low
Penncozeb DF mancozeb		Low			Low		Low
Polyram metiram	Low			Low	Low		Harmful
Rebound WP propineb + oxadixyl	Low				Low		Low
Thiovit elemental sulphur	Low	Low	Low		Low		
Herbicide Product & active ingredient							
Select clethodim		Harmful			Low		

KEY **Low** **Moderately harmful** **Harmful**

- Low (green)
- Moderately harmful (yellow)
- Harmful (red)

RECOMMENDATIONS

The key intention of this project was to improve awareness that successful IPM in crops relies heavily on preserving the beneficial species that can exert biological control of pests. The judicious application of pesticides is critical to preserving these natural enemies. We recommend:

- Consideration of pesticide impacts on beneficial insects and mites in crops should be part of decision making for all spray applications.
- Application of insecticides should be considered as a back-up to other pest control strategies such as biological and cultural controls.
- Selective insecticides should be chosen whenever beneficial species are capable of exerting control pressure on pest species.
- Growers and advisors need better understanding of the beneficial species present in their crops and to achieve this requires monitoring of crops and education in insect identification.
- The pesticide charts and information developed in this project should be consulted to help choose the most appropriate pesticide in terms of preserving beneficial species.
- Field application factors, such as multiple applications of the same product or tank-mixing of products could change the pesticide impacts on certain beneficial species.
- There is a continuous need for researchers to test currently registered pesticides with beneficial species to improve the knowledge base available to industry. Additionally, new pesticides are being developed, current pesticides gain registration in different crops, and new pest issues arise which all create further need for pesticide testing.
- The online pesticide charts and information need to be made more accessible and be available to the public rather than just vegetable levy payers. This will greatly improve the adoption of this research.
- Further promotion of the research outcomes could be achieved through presentations at grower meetings and industry workshops Australia-wide.

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