Efficacy of insecticides against the tomato/potato psyllid (*Bactericera cockerelli*)

N.E.M. Page-Weir, L.E. Jamieson, A. Chhagan, P.G. Connolly and C. Curtis

The New Zealand Institute for Plant & Food Research Limited (Plant & Food Research), Private Bag 92169, Auckland
Corresponding author: Lisa.Jamieson@plantandfood.co.nz

Abstract Adult and nymphal life stages of the tomato/potato psyllid (*Bactericera cockerelli*; TPP) cause damage to the host plants and transmit the bacterial pathogen '*Candidatus* Liberibacter solanacearum'. This leads to reduced crop yield and ultimately the premature decline and death of the infected plant. The efficacy of 11 insecticides was tested against nymphal and adult stages of TPP. Residues of abamectin + oil and bifenthrin were the most effective at reducing adult TPP up to 3 days after treatment, while thiacloprid, spiromesifen, imidacloprid, spinetoram and azadirachtin were slightly toxic. Residues of buprofezin + oil, pyrethrin + oil and mineral oil had no effect on adult mortality. Nymphal life stages were best controlled with abamectin + oil, spirotetramat, bifenthrin and spiromesifen.

Keywords tomato/potato psyllid, *Bactericera cockerelli*, insecticides, abamectin, spirotetramat, bifenthrin, spiromesifen, oil.

INTRODUCTION

The tomato/potato psyllid (TPP), *Bactericera cockerelli* (Hemiptera: Psyllidae), was first identified in New Zealand in 2006 (MAF Biosecurity 2009). Since its discovery, TPP has spread throughout many regions of New Zealand, infesting plants in the Solanaceae and some species of Convolvulaceae (Liefting et al. 2009; MAF Biosecurity 2009).

Feeding of both the adult and nymphal life stages of TPP on the leaves of host plants results in damage by two mechanisms. Firstly, TPP is thought to cause 'psyllid yellows' as seen in tomatoes and potatoes, which results in yellowing of leaves and stunted growth (Brown et al. 2010; Sengoda et al. 2010). Secondly, TPP facilitates transmission of the bacterial pathogen '*Candidatus* Liberibacter solanacearum', which is the causative agent of zebra chip disorder in potato tubers (Munyaneza et al. 2007; Abad et al. 2009; Sengoda et al. 2010), and results in leaf curling and yellowing as well as stunted growth in the fruit of tomatoes and capsicums (MAF Biosecurity 2008; Brown et al. 2010). '*Candidatus* Liberibacter solanacearum' infection not only reduces crop yield and affects the quality of the fruiting body, but ultimately also leads to the decline and death of the infected plant (Sengoda et al. 2010).

Investigations are underway to understand the phenology of TPP in various regions of New Zealand, its host range and transmission biology (N.A. Berry, Plant & Food Research, pers. comm.). This information, in conjunction with the development of spray programmes targeted to the susceptible life stages of psyllids, will help growers to make informed decisions about when to spray their crops and control

TPP most effectively and ultimately lead to the establishment of an IPM programme.

This paper presents results from a trial carried out on potted capsicum plants to determine the efficacy of various insecticides against TPP. Insecticides were chosen from a mixture of chemical groups with different properties for insect control.

MATERIALS AND METHODS

Experimental details

Adult TPP of mixed sex were released into a glasshouse unit with capsicum plants (McGregors 'Californian Wonder') to allow egg laying. These eggs were left to hatch so that after 2 weeks there was a mixture of eggs and early instar nymphs on plants. This was done in preference to manually infesting plants with psyllids as previous work had revealed that eggs and early nymphs could be damaged when handling. Late instar nymphs, from a laboratory colony, were transferred onto plants using a fine tipped paintbrush so that a minimum of 15 late instar nymphs were on each plant. Plants were assigned treatments (Table 1) and moved to an outdoor spray area to ensure no spray drift between treatments. Treatment rates were based on label rates or those agreed on in consultation with growers.

Four litres of each treatment was mixed and applied using a 5 litre hand sprayer. On 3 June 2010, treatments were applied starting at the uppermost leaves and working towards the base of the plant, ensuring that the top of each leaf was sprayed but that there was minimal spray run-off. Four replicate plants were treated with each treatment. The control plants received no treatment.

Plants were left outside for approximately 3 h to dry before being moved back into a glasshouse where the temperature was held between 25–30°C. Plants were placed into treatment groups and enclosed within a mesh cage. At this time an additional 40 adult TPP of mixed sex were enclosed in a small mesh bag over a leaf on each plant to test residue activity. The numbers of live and dead adults in these bags were counted 3 days after treatment. The numbers of live or dead TPP nymphs on each plant were assessed 1, 2, 4, 6, 8, 10 and 12 weeks after treatment.

On 30 July 2010, spirotetramat treatments were similarly carried out (delayed due to incorrect rate applied on 3 June) and compared with separate controls set up at that time. All plants were sprayed and assessed using the methods described above.

By 8 weeks after treatment untreated control plants had significantly deteriorated due to high TPP infestation. Numbers of TPP on controls began to decline as the plants died. All control plants were dead at 12 weeks. Due to this, only data from the first 6 weeks of monitoring are presented when the plants were seen to be healthy.

Table 1 The active ingredient, trade name and rate of treatments.

Treatment (ai)	Trade name	Rate (ai/100 litres)
Untreated control		
abamectin+oil	Avid® + mineral oil	70 ml + 500 ml
thiacloprid	Calypso®	60 ml
imidacloprid	Confidor®	0.1 ml in 100 ml [1]
spinetoram	Delegate®	10 g
azadirachtin	NeemAzal – T/S™	500 ml
buprofezin+oil	Ovation™50WDG + mineral oil	25 g + 500 ml
bifenthrin	Talstar®	40 ml
pyrethrin + oil	Pyradym® + mineral oil	50 ml + 25 ml
spiromesifen	Oberon®	60 ml
mineral oil	DC-Tron®	1000 ml
spirotetramat + oil polymer	Movento® + Partner®	40 ml + 50ml

[1]Applied per plant as a soil drench.

Statistical analysis

Percentage mortalities of adults exposed to residues were angular transformed and then compared between treatments using analysis of variance (ANOVA). Least significant differences (LSDs) were calculated to separate treatments where the ANOVA demonstrated significant differences ($P<0.05$). Transformed percentage mortalities of adults exposed to spirotetramat residues were analysed separately and compared to transformed mortalities of adults in untreated plants set up at the same time (control 2). The analysis was performed using GenStat (version 10) ((PC/Windows XP) Copyright 2006, Lawes Agricultural Trust (Rothamsted Experimental Station)).

Differences in populations of early and late nymphs were assumed to be influenced only by the treatment and the number at day zero. It was assumed that differences between the quality of the plant material in the various treatments was negligible during the 6-week period investigated. Numbers of nymphs on the days in question, relative to the number on day zero, were analysed to compare the treatments with the control group. Two proportions were compared:

T_t/T_0 and C_t/C_0 where:

T_t = number of nymphs on treated plants at time t, T_0 = number of nymphs on treated plants at time 0, C_t = number of nymphs on untreated control plants at time t, and C_0 = number of nymphs on untreated control plants at time 0.

The R version 2.12.1 (R Development Core Team) generalized linear model used the negative binomial model to adjust for the high levels of overdispersion. Because of the necessary approximations made in the assumptions (number of TPP not influenced by plant quality), the Type I error rate was set at 0.01 to lessen the possibility of spurious differences. For the spirotetramat experiment, the numbers of nymphs were compared with those on control plants by a pairwise t-test.

RESULTS

Adult mortality

Residues of abamectin + oil and bifenthrin resulted in significantly ($P<0.001$) higher adult mortality than residues from other treatments and controls, with 85–93% of adults dead 3 days after treatment (Figure 1). Adult TPP mortality on leaves with residues of pyrethrin + oil, mineral oil, buprofezin + oil or spirotetramat was not significantly different ($P\geq0.05$) from that on untreated leaves (Figure 1).

Nymphal mortality

Table 2 summarises the mean number of nymphs on treated and untreated plants. There were differences in nymph numbers between plants allocated to treatments prior to spray application, therefore the proportion of nymphs on plants compared with day zero is presented in Table 3.

At 1 and 2 weeks after treatment, buprofezin + oil-, mineral oil-, azadirachtin-, bifenthrin-, abamectin + oil- and thiacloprid-treated plants had a lower proportion of live TPP compared with the untreated control. However, by 4 weeks after treatment the proportion of TPP on buprofezin + oil- and mineral oil-treated plants had begun to increase and there was no longer a significant difference when compared with the controls (Table 3). The azadirachtin-treated

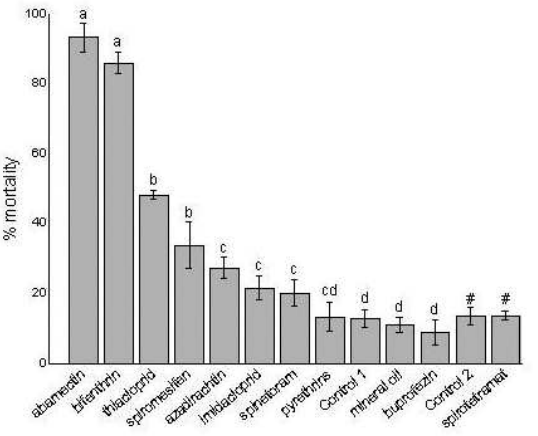

Figure 1 The percentage mortality of tomato/potato psyllid (*Bactericera cockerelli*) adults 3 days after treatment on capsicums. Vertical lines represent the standard errors of the means. Means followed by the same letter are not significantly different at $P=0.05$. The bars indicated by # are from a later spirotetramat experiment where the control and treatment were not significantly different from each other.

Table 2 The mean number (±SEM) of tomato/potato psyllid (*Bactericera cockerelli*) nymphs before and after treatment.

	Post treatment assessments (weeks)				
Treatment	0	1	2	4	6
Control	215.25 ± 66.24	265 ± 45.08	384.75 ± 54.25	210.25 ± 39.74	343.5 ± 60.11
buprofezin+ oil	127.75 ± 26.46	68.25 ±5.41	37 ± 4.30	122.25 ± 22.61	216.5 ± 68.33
mineral oil	94.25 ± 39.78	60.25 ± 17.78	31.25 ± 7.09	55.25 ± 15.55	149.5 ± 25.14
spiromesifen	93.50 ± 9.72	121.25 ±26.79	15 ± 4.67	3.25 ± 1.97	4.5 ± 4.5
azadirachtin	102.25 ± 14.01	54.5 ± 11.76	52.75 ± 10.97	67.75 ± 15.73	67 ± 20.19
imidacloprid	73.25 ± 15.10	174 ± 32.05	91.5 ± 20.40	46.75 ± 6.47	71.25 ± 20.67
spinetoram	93.75 ± 11.24	169.75 ± 28.78	84.5 ± 14.62	46.25 ± 6.71	122 ± 15.04
bifenthrin	73.75 ± 10.68	7 ± 1.47	4.75 ± 2.13	3.5 ± 2.22	6.25 ± 3.06
pyrethrin+ oil	99.50 ± 10.74	92.5 ± 14.23	74.25 ± 17.93	42.25 ± 9.63	202.75 ±30.84
thiacloprid	161.75 ± 25.05	85.5 ± 16.66	57.25 ± 7.88	56.5 ± 3.40	249.75 ± 47.22
abamectin+ oil	205.75 ± 27.49	17.25 ± 5.22	0.75 ± 0.75	5 ± 4.36	0 ± 0
Control 2	113.75 ± 24.76	149 ± 13.68	358 ± 60.64	122.5 ± 11.82	161.25 ± 52.96
spirotetramat	120 ± 22.15	60.75 ± 18.13	14.25 ± 11.74	25.5 ± 11.75	0 ± 0

plants still had a significantly lower proportion of TPP than the control at week 6, largely due to the increase in numbers in the control at this time compared to day 0. Thiacloprid had a significantly lower proportion of TPP for up to 4 weeks after treatment.

Spinetoram treatment resulted in a significantly lower proportion of nymphs at week two only. Two weeks after treatment numbers of nymphs on spiromesifen- and spirotetramat + oil-treated plants had significantly reduced and remained lower than on untreated plants for up to 6 weeks. Pyrethrin + oil-treated plants showed a significant difference in TPP infestation when compared with untreated controls at 2 and 4 weeks, but by 6 weeks there was no longer a difference between treatments and untreated controls.

By 6 weeks all TPP nymphs were dead on abamectin + oil- and spirotetramat-treated plants and numbers of nymphs on spiromesifen-, azadirachtin- and bifenthrin-treated plants remained significantly lower than on untreated plants.

Numbers of TPP nymphs on imidacloprid-treated plants were not significantly different from that on untreated controls at any of the assessment times.

DISCUSSION

The residual activity of insecticides is important against highly mobile pest life stages, such as TPP adults, which can avoid direct exposure and re-infest plants soon after application. Abamectin + oil and bifenthrin residues resulted in high mortality (>80%) of TPP adults. Although the mineral oil treatment in the present study had no significant effect on adult mortality, some mineral oils have been shown to have repellent effect on TPP and reduced oviposition on tomato for up to 3 days after treatment (Yang et al. 2010). The persistence of insecticidal residues against TPP adults and nymphs and their impact on TPP egg laying, feeding and transmission of '*Candidatus* Liberibacter solanacearum' is currently being investigated (N.E.M. Page-Weir, Plant & Food Research, pers. comm.).

Of the 11 products tested, abamectin + oil, bifenthrin, spiromesifen and spirotetramat gave effective control of TPP nymphs over a 6-week period. Abamectin + oil and bifenthrin had a good knockdown effect against TPP nymphs, while spiromesifen and spirotetramat took a couple of weeks to become effective. These results support those reported in previous bioassays on TPP nymphs where abamectin (Vega-Gutierrez et al. 2008; Berry et al. 2009;

Table 3 The relative difference of numbers of tomato/potato psyllid (*Bactericera cockerelli*) nymphs on each treatment compared to time 0. Values >1 indicate an increase in number of TPP, while values < 1 indicate a decrease in number of TPP from the start of the experiments.

	Post treatment assessments (weeks)			
Treatment	1	2	4	6
Control 1	1.23	1.79	0.98	1.60
buprofezin + oil	0.53*[1]	0.29*	0.96	1.69
mineral oil	0.64*	0.33*	0.59	1.59
spiromesifen	1.30	0.16*	0.03*	0.05*
azadirachtin	0.53*	0.52*	0.66	0.66*
imidacloprid	2.38	1.25	0.64	0.97
spinetoram	1.81	0.90*	0.49	1.30
bifenthrin	0.09*	0.06*	0.05*	0.08*
pyrethrin + oil	0.93	0.75*	0.42*	2.04
thiacloprid	0.53*	0.35*	0.35*	1.54
abamectin + oil	0.08*	0.00*	0.02*	0.00*
Control 2	1.31	3.15	1.08	1.42
spirotetramat	0.51	0.12*	0.21*	0.00*

[1] * indicates a significant difference ($P \leq 0.01$) between a treatment and the appropriate control. To determine a significant difference two proportions were compared: T_t/T_0 and C_t/C_0 where: T_t = number of nymphs on treated plants at time t, T_0 = number of nymphs on treated at time 0, C_t = number of nymphs on untreated control plants at time t, and C_0 = number of nymphs on untreated control plants at time 0.

Walker & Berry 2009) and spirotetramat (Berry et al. 2009) treatment resulted in effective control of TPP. Effective control of pear psyllids (*Psylla pyri*) using spirotetramat has also been reported (Brück et al. 2009). Previous studies have also shown spiromesifen to give good control of TPP (Berry et al. 2009; Walker & Berry 2009; Tucuch-Haas et al. 2010).

Buprofezin + oil and the mineral oil treatment controlled TPP nymphs for up to 2 weeks after treatment. These results support those reported in Berry et al. (2009), where 44% nymphal mortality was recorded at 7 days after treatment with buprofezin. Treatment with azadirachtin reduced abundance of TPP nymphs as was shown in a laboratory bioassay (Berry et al. 2009). The use of low mammalian toxicity products, such as mineral oil and azadirachtin, may be effective when incorporated with other control strategies (e.g. biocontrol, plant resistance, early season harvest window) as part of an IPM programme.

Soil application of imidacloprid has been found to have a significant impact on immature stages of the Asian citrus psyllid (*Diaphorina citri*) on citrus trees (Sétamou et al. 2010) and has resulted in 53% mortality of TPP nymphs on capsicum seedlings after 7 days. In this study imidacloprid treatment did not result in a significant reduction in numbers of TPP nymphs indicating that the rate applied and therefore taken up by the plant may not have been high enough.

Very little peer reviewed material on the efficacy of insecticides against psyllids, in particular TPP, is available. Most published research has been undertaken in the United States, Mexico and Central America where growing conditions are very different to New Zealand and many of the insecticides available are different from those registered in New Zealand. Therefore, trials testing the efficacy of insecticides used in New Zealand against TPP are an important step towards the establishment of an IPM programme for affected industries, and ongoing research is required.

ACKNOWLEDGEMENTS

We would like to thank Peter Workman, Frances McDonald, Robin Gardner-Gee and Ngaire Larsen of Plant & Food Research for providing helpful advice, psyllids and plants; Craig Watson of New Zealand Tamarillo Growers' Association for discussions about insecticides suitable for tamarillos; Peter Lo for comments on the manuscript; and the Ministry of Agriculture and Forestry Sustainable Farming Fund and New Zealand Tamarillo Growers' Association for supporting this research.

REFERENCES

Abad JA, Bandla AM, French-Monar RD, Liefting LW, Clover GRG 2009. First report of the detection of *Candidatus* Liberibacter species in zebra chip disease infected potato plants in the United States. Plant Disease 93: 108.

Berry NA, Walker MK, Butler RC 2009. Laboratory studies to determine the efficacy of selected insecticides on tomato/potato psyllid. New Zealand Plant Protection 62: 145-151.

Brown JK, Rehman M, Rogan D, Martin RR, Idris AM 2010. First report of "*Candidatus* Liberibacter psyllaurous" (synonym "*Ca.* L. solanacearum") associated with 'tomato vein-greening' and 'tomato psyllid yellows' diseases in commercial greenhouses in Arizona. Plant Disease 94: 376-376.

Brück E, Elbert A, Fischer R, Krueger S, Kuhnhold J, Klueken AM, Nauen R, Niebes JF, Reckmann U, Schnorbach HJ, Steffens R, van Waetermeulen X 2009. Movento (R), an innovative ambimobile insecticide for sucking insect pest control in agriculture: Biological profile and field performance. Crop Protection 28: 838-844.

Liefting LW, Weir BS, Pennycook SR, Clover GRG 2009. '*Candidatus* Liberibacter solanacearum', associated with plants in the family Solanaceae. International Journal of Systematic and Evolutionary Microbiology 59: 2274-2276.

MAF Biosecurity 2008. New bacterium affects fresh tomatoes and capsicums. http://www.biosecurity.govt.nz/pests/surv-mgmt/resp/tom-cap-bacterium (accessed 5 May 2011).

MAF Biosecurity 2009. Potato/Tomato Psyllid *Bactericera cockerelli*. http://www.biosecurity.govt.nz/pests/potato-tomato-psyllid (accessed 5 May 2011).

Munyaneza JE, Crosslin JM, Upton JE 2007. Association of *Bactericera cockerelli* (Homoptera: Psyllidae) with "zebra chip" a new potato disease in southwestern United Staes and Mexico. Journal of Economic Entomology 100: 656-663.

Sengoda VG, Munyaneza JE, Crosslin JM, Buchman JL, Pappu HR 2010. Phenotypic and etiological differences between psyllid yellows and zebra chip diseases of potato. American Journal of Potato Research 87: 41-49.

Sétamou M, Rodriguez D, Saldana R, Schwarzlose G, Palrang D, Nelson SD 2010. Efficacy and uptake of soil-applied imidacloprid in the control of asian citrus psyllid and a citrus leafminer, two foliar-feeding citrus pests. Journal of Economic Entomology 103: 1711-1719.

Tucuch-Haas JI, Rodriguez-Maciel JC, Lagunes-Tejeda A, Silva-Aguayo G, Aguilar-Medel S, Robles-Bermudez A, Gonzalez-Camacho JM 2010. Toxicity of spiromesifen to the developmental stages of *Bactericera cockerelli* (Sulc) (Hemiptera: Triozidae). Neotropical Entomology 39: 436-440.

Vega-Gutierrez MT, Rodriguez-Maciel JC, Diaz-Gomez O, Bujanos-Muniz R, Mota-Sanchez D, Martinez-Carrillo JL, Lagunes-Tejeda A, Garzon-Tiznado JA 2008. Susceptibility to insecticides in two Mexican populations of tomato-potato psyllid, *Bactericera cockerelli* (Sulc.) (Hemiptera : Triozidae). Agrociencia 42: 463-471.

Walker MK, Berry NA 2009. Insecticides have potential for tomato/potato psyllid control. Grower 64: 27-28.

Yang XB, Zhang YM, Hua L, Peng LN, Munyaneza JE, Trumble JT, Liu TX 2010. Repellency of selected biorational insecticides to potato psyllid, *Bactericera cockerelli* (Hemiptera: *Psyllidae*). Crop Protection 29: 1320-1324.