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Tomato potato psyllid – contact insecticide efficacy

Watkins L, Drayton G, Butler R, Kean A, Preddey J, Vereijssen J

December 2021

Confidential report for:

Potatoes New Zealand Incorporated
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The Canterbury Potato Liberibacter Initiative received reports in the 2020/2021 growing season that some Canterbury tomato potato psyllid (TPP, *Bactericera cockerelli* (Šulc)) populations were not responding to the insecticide programmes as would normally be expected. It is unclear if this is caused by reduced efficacy of the insecticides or by other factors.

The aim of the project was to investigate whether selected contact insecticides at label rate were efficacious on a field-collected population of TPP from Canterbury.

The trial was set up in a controlled climate room at Plant & Food Research (PFR) Lincoln (22°C, 40-60% RH, 16:8 h L:D) in experimental containers with a filter paper placed on the inner base. A small opening in the lid allowed for adult TPP transfer and the application of products. These openings were sealed with Micropore™ tape during the trial. A 'wild' TPP population was collected by Seed & Field Services Limited on Canterbury potato crops at sites showing a perceived lack of control of TPP. One-hundred and eight adults or fourth and fifth instar nymphs from this population were tested for each insecticide and compared with the same life stages from a susceptible PFR TPP lab colony. MAVRIK® AQUAFLO, Karate Zeon®, Pirimor® 50, Benevia®, Oberon®, Methafos 600, and Sparta™ were applied at label rate to the life stages. At 2, 19, 25, 43 and 48 h after product application, each individual of each life stage was recorded as live, moribund, or dead.

The results from the contact insecticide trial showed no material difference in mortality of adults and nymphs between the 'wild' field-collected colony and the susceptible PFR TPP colony for all products tested. Therefore, the perceived lack of control of TPP in Canterbury may have been due to other factors.

A follow-up trial testing systemic and translaminar insecticides currently used to manage TPP in potato crops will be conducted in early 2022, using the same two TPP colonies.

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1 Introduction

The Canterbury Potato Liberibacter Initiative (CPLI) received reports in the 2020/2021 growing season that some Canterbury tomato potato psyllid (TPP, *Bactericera cockerelli* (Šulc)) populations were not responding to the insecticide programmes as would generally be expected. It is unclear if this is caused by reduced efficacy of the insecticides or by other factors. Reduced effectiveness of spray programmes will probably result in a high incidence of zebra chip disease, putatively caused by the plant pathogenic bacterium *Candidatus* Liberibacter solanacearum (CLso) transmitted by TPP. Zebra chip disease makes the tubers unsuitable for processing (e.g. fries, crisps), causes disease in seed tubers, and is perceived to affect the taste of fresh market potatoes and their internal appearance.

The aim of the project was to investigate whether selected contact insecticides at label rate were efficacious on a field-collected population of TPP from Canterbury.

2 Materials and methods

2.1 Tomato potato psyllid populations used

In this trial, TPP adults and nymphs were collected from two TPP colonies:

1. A ‘wild’ field-collected TPP colony with putative reduced sensitivity to insecticides
2. A ‘susceptible’ PFR TPP lab colony (control).

Seed & Field Services Limited collected the 'wild' population on potato crops at sites showing perceived lack of control of TPP in Canterbury. All adults and instars collected, and their offspring, have been maintained as a colony at PFR since March 2021 on bell peppers, *Capsicum annuum* ‘Giant Bell’ in a controlled growth room (25°C, 16:8 h Light:Dark (L:D), and 40–50% relative humidity (RH)). On 9 September 2021, 20 adult TPP from the ‘wild’ colony were collected and screened the following day for CLso using a quantitative polymerase chain reaction (qPCR) (Beard & Scott 2013) to inform decisions on whether a CLso-positive or negative ‘susceptible’ PFR control colony would be used. All individuals tested negative for CLso. Hence, psyllids from the CLso-negative PFR lab colony were used for this trial.

The ‘susceptible’ laboratory colony has not been subjected to insecticidal pressure, as it has been in colony at The New Zealand Institute for Plant and Food Research Limited (PFR) since 2010. This colony has consistently tested negative in our routine testing regime for CLso; ten randomly selected TPP per cage (four cages total) have been tested for CLso every 5 (historical) to 10 (last two years) weeks, first following the multiplex PFR protocol by Liefting et al. (2009), later using the DNA extraction and qPCR protocols developed by Beard & Scott (2013), and as of September 2019 migrating to a multiplex probe-based qPCR assay with internal primers by Thompson et al. (unpublished) and CLso primers by Li et al. (2009).

2.2 Insecticides

The seven products tested were: MAVRIK® AQUAFLO, Karate Zeon®, Pirimor® 50, Benevia®, Oberon®, Methafos 600, and Sparta™. Please refer to Appendix A. for supplementary information on each insecticide, including mode and primary sites of action, and Appendix B for the label specifications of each product. Liquids for all products were directly applied to TPP inside the container using a handheld atomiser with an operating pressure sitting at around 137 kPa (~20 psi). The dilution of each product was determined through area-based calculations to obtain concentrations corresponding to field doses for each container. All liquids were mixed as per label and client recommendations using reverse osmosis (RO) water. Non-ionic surfactants/wetting agents were not added to mixes, after discussions with CPLI.

2.3 Trial plan and set up

The trial was set up in a controlled climate room at PFR Lincoln (22°C, 40-60% RH, 16:8 h L:D). Experimental containers (8.0 cm diameter, 6.0 cm high; total surface area 251.33 cm; Figure 1) were laid out over two benches using a Latinized resolvable row-column design (Figure 2; CycDesigN, VSN International, 2013), spaced 4 cm apart. Filter papers were fixed to the inner bases of each container to protect insects against excess moisture from product application. All containers had lids with a small opening in the centre, used during adult TPP transfer and for applying products via an airbrush to prevent escapees. These openings were sealed with breathable Micropore™ tape during the trial.

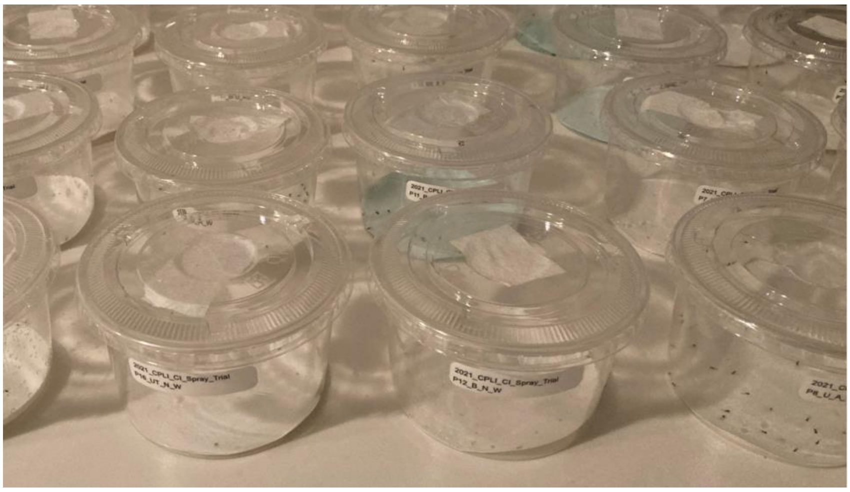

Figure 1. Plastic containers used in the trial, each with filter paper secured on the inner base and 35 tomato potato psyllid individuals of either adult or fourth-fifth instar nymphs.

Rep 1

1 UT_Nc	2 UT_Aw	3 MA_Nw	4 M_Ac
5 P_Ac	6 P_Nw	7 WC_Nc	8 S_Aw
9 M_Nc	10 MA_Ac	11 P_Aw	12 B_Nw
13 O_Ac	14 B_Nc	15 B_Aw	16 UT_Nw
17 B_Ac	18 S_Nc	19 O_Nw	20 K_Aw
21 K_Nw	22 K_Ac	23 M_Aw	24 O_Nc
25 S_Nw	26 O_Aw	27 UT_Ac	28 MA_Nc
29 MA_Aw	30 WC_Nw	31 K_Nc	32 WC_Ac
33 WC_Aw	34 M_Nw	35 S_Ac	36 P_Nc

Rep 2

37 B_Nc	38 K_Nw	39 P_Ac	40 O_Aw
41 MA_Nw	42 WC_Ac	43 S_Nc	44 M_Aw
45 M_Ac	46 B_Aw	47 M_Nw	48 K_Nc
49 K_Aw	50 S_Ac	51 B_Nw	52 UT_Nc
53 WC_Nw	54 M_Nc	55 UT_Aw	56 B_Ac
57 S_Aw	58 O_Nw	59 O_Ac	60 WC_Nc
61 P_Aw	62 P_Nc	63 K_Ac	64 S_Nw
65 O_Nc	66 UT_Nw	67 WC_Aw	68 MA_Ac
69 UT_Ac	70 MA_Aw	71 MA_Nc	72 P_Nw

Rep 3

73 B_Aw	74 O_Nc	75 S_Nw	76 WC_Ac
77 O_Nw	78 UT_Aw	79 P_Nc	80 MA_Ac
81 K_Ac	82 WC_Nc	83 MA_Nw	84 O_Aw
85 P_Ac	86 MA_Aw	87 B_Nw	88 S_Nc
89 WC_Nw	90 S_Ac	91 M_Aw	92 B_Nc
93 MA_Nc	94 P_Nw	95 WC_Aw	96 M_Ac
97 S_Aw	98 B_Ac	99 K_Nc	## UT_Nw
## UT_Nc	## M_Nw	## O_Ac	## P_Aw
## M_Nc	## K_Aw	## UT_Ac	## K_Nw

Figure 2. The layout of the trial in three replicates (Rep) inside the controlled climate room. Each square represents one container (spaced at least 4 cm apart), and the number (top left) represents the container number. The letters inside the square refer to the treatment combination code (refer to Table 1 for the list of products, combination codes, colonies and life stages that each combination code represents).

Thirty-five TPP individuals were counted and carefully deposited into each container. Individuals corresponded to the treatment allocated to each container, selecting either adult or fourth-fifth instar nymph from either the 'wild' or control PFR colony. Adults were caught directly from the colony cages in batches of five or ten using Eppendorf tubes and deposited through the top opening of the container. Capsicum leaves containing nymphs were removed from the colony cages and transferred to plastic lunch boxes for nymph collection. Individual fourth-fifth instar nymphs were nudged using a wetted fine-pointed paintbrush until movement was observed. Then individuals were carefully transferred with the paintbrush directly onto the filter paper inside the container. This paintbrush method was used to prevent damage to the insect, especially their stylet (sucking mouthpart) being broken off from their head (i.e. stylectomy) if they were feeding at the time of removal.

2.4 Treatments

The bioassay involved testing the lethal effects of seven contact insecticides against two life stages of TPP, adults and fourth-fifth instar nymphs. Information on their collection from the colonies is detailed under Section 2.3. TPP released inside the experimental containers were sprayed with their associated product on 19 October 2021 using a hand-held atomiser. TPP were dislodged from the lid just before applying a product by tapping the whole container on the bench to dislodge adults, or tapping the lid to dislodge nymphs. During application containers with adults were tapped on the bench several times to ensure TPP were in direct contact with the product. A fine mist was created by the atomizer which settled shortly after spraying for all treatments. Tapping during application was not necessary for nymphs as they were not as mobile and settled on the filter paper long enough for product application. Since the trial ran for a short period (48 hours), starvation should not have influenced mortality to such an extent that the effects of direct contact with an insecticide would not be seen between treatments. This 'natural' mortality is captured with the Untreated control treatment.

The trial contained 36 different treatments, each a combination of product application, TPP life stage, and TPP colony treatment (Table 1). Each treatment was replicated three times. A total of 735 TPP adults and 735 TPP nymphs from each colony were subjected to a specific insecticide. The rest were exposed to either an RO water application (to measure spray effect) or an untreated/no spray control (to measure natural/background mortality rate).

Table 1. Treatments for tomato potato psyllid (TPP) ordered by insecticide treatment and TPP life stage. For the combination code column, the first letter/s before the underscore: product applied, see column "Product". First letter after underscore: A = TPP adult; N = TPP nymph. Second letter after underscore: W = Wild field-collected TPP colony provided by Seed & Field Services Limited (putative reduced sensitivity to insecticides); C = Plant & Food Research (PFR) lab colony that has been in a colony at PFR since 2010 (susceptible).

Treatment number	Combination code	Product	TPP life stage	TPP colony
1	MA_AW	MAVRIK® AQUAFLO	Adult	Wild colony
2	MA_AC	MAVRIK AQUAFLO	Adult	PFR colony
3	MA_NW	MAVRIK AQUAFLO	Nymph	Wild colony
4	MA_NC	MAVRIK AQUAFLO	Nymph	PFR colony
5	K_AW	Karate Zeon®	Adult	Wild colony
6	K_AC	Karate Zeon	Adult	PFR colony
7	K_NW	Karate Zeon	Nymph	Wild colony
8	K_AC	Karate Zeon	Nymph	PFR colony
9	P_AW	Pirimor® 50	Adult	Wild colony
10	P_AC	Pirimor 50	Adult	PFR colony
11	P_NW	Pirimor 50	Nymph	Wild colony
12	P_AC	Pirimor 50	Nymph	PFR colony
13	B_AW	Benevia®	Adult	Wild colony
14	B_AC	Benevia	Adult	PFR colony
15	B_NW	Benevia	Nymph	Wild colony
16	B_NC	Benevia	Nymph	PFR colony
17	O_AW	Oberon®	Adult	Wild colony
18	O_AC	Oberon	Adult	PFR colony
19	O_NW	Oberon	Nymph	Wild colony
20	O_NC	Oberon	Nymph	PFR colony
21	M_AW	Methafos 600	Adult	Wild colony
22	M_AC	Methafos 600	Adult	PFR colony
23	M_NW	Methafos 600	Nymph	Wild colony
24	M_NC	Methafos 600	Nymph	PFR colony
25	S_AW	Sparta™	Adult	Wild colony
26	S_AC	Sparta	Adult	PFR colony
27	S_NW	Sparta	Nymph	Wild colony
28	S_NC	Sparta	Nymph	PFR colony
29	WC_AW	Water control	Adult	Wild colony
30	WC_AC	Water control	Adult	PFR colony
31	WC_NW	Water control	Nymph	Wild colony
32	WC_NC	Water control	Nymph	PFR colony
33	UT_AW	Untreated (no spray) control	Adult	Wild colony
34	UT_AC	Untreated (no spray) control	Adult	PFR colony
35	UT_NW	Untreated (no spray) control	Nymph	Wild colony
36	UT_NC	Untreated (no spray) control	Nymph	PFR colony

2.5 Insect assessments

Numbers of live, moribund and dead TPP adults and nymphs per container were recorded five times over a 48-h period at 2, 19, 25, 43 and 48 h after applying the products. Each TPP in a container was recorded as:

- Dead: no movement of an individual during a ~15-s observation (legs usually curled under)
- Moribund: twitching or very slow movement of an individual
- Alive: normal, reasonable movement (even if stuck in liquid drop).

All containers were assessed inside a fume hood by tapping the container on the bench and checking for movement. The opening of some containers had widened after spraying, exposing some TPP to the underside (sticky side) of the Micropore tape during the trial. A high number of TPP on tape in the water control (WC) were alive through to the end of the trial indicating there was no great detrimental effect to the insect, and there were no TPP on the tape before spraying, i.e. TPP on tape were exposed to the products applied. Therefore TPP stuck on the tape were assessed as above and included in the totals for “Dead”, “Moribund”, and “Alive”. Subsequent finger taps were carried out to check individuals for further movement if required. For each container, assessors waited ~15 seconds for individuals to move. Live nymphs and adults had noticeably higher mobility than moribund, and adults were far easier to assess. Occasionally nymphs required nudging to distinguish between dead and moribund. Individual fine pieces of wire were used for nudging TPP, one wire allocated to each treatment to avoid cross-contamination between treatments. Since the total number of TPP per container was relatively high when considering the accuracy of counts (especially for mobile insects), counts during scoring were performed by first choosing the state that was easiest to count inside each container (e.g. if most were alive, dead and moribund were counted first). This was done so that counts were as accurate as possible and were carried out within a reasonable time frame. The total number of individuals in each container was counted at the end of the experiment after freezing.

2.6 Methods of analysis

Results for all five assessment times were explored graphically only. Formal analysis was carried out only for assessments conducted at 19 h and 48 h, the final assessment.

For simplicity of analysis and presentation of results, only data for 19 h and 48 h were examined, and these were analysed separately. It is clear from the results that analysis of the other assessment times would add little extra information, since the final patterns in the results had appeared by 19 h (Figure 3). The numbers of TPP alive, dead, moribund and on the tape were each analysed with a binomial generalized linear model (McCullagh & Nelder 1989), with a logit link and dispersion estimated, and using the total numbers of TPP in the container as the binomial total. In addition, product, life stage, colony, and interactions were assessed with F-tests carried out with an analysis of deviance done as part of the analyses. Various other comparisons were also made similarly.

In the Results section, the means are presented with associated 95% confidence limits. These were obtained on the link (logit) scale and transformed to percentages.

The analyses were carried out with Genstat Release 21 (Payne et al. 2020).

3 Results

In most cases, the pattern of results for "Dead" at 19 h after applying the products remained relatively similar to the pattern at the final assessment at 48 h (Figure 3). All adults and nymphs were dead by 19 h for MAVRIK AQUAFLO, Karate, Methafos, and Sparta. For products other than Oberon and Water Control, the changes over assessments were broadly similar for the two life stages and colony sources.

At 19 h, the percentages of TPP alive, dead and moribund, averaged over life stages and colony, varied between products ($p>0.001$). There were also overall differences between life stages ($p<0.001$; $p<0.001$; $p=0.045$ respectively, for alive, dead and moribund). However, the differences between the two life stages varied with the different products ($p<0.001$; $p<0.001$; $p=0.002$ for alive, dead and moribund for the interaction between product and life stage):

- Adult TPP exposed to Oberon had a higher survival rate than did nymphs (as measured by % alive and dead).
- There were generally more moribund nymphs than adults (Figure 4), except with Pirimor (where the opposite was true), and in the controls (WC and UT) and with Methafos, where there were no moribund insects at 19 h.

Colony effects (i.e. wild versus PFR colony) were present but relatively smaller at 19 h ($p>0.05$) for each of the colony main effect and interactions involving colony.

At 19 h, the numbers of TPP stuck on the tape differed substantially with product and life stage, with the product and life stage effects varying with the different colonies ($p=0.001$, $p=0.027$ for the Product Colony and Life stage.Colony interactions respectively). On average, more nymphs were found on the tape with Pirimor, Oberon and the Water Control than with the other products (Appendix C). For the adults, on average more of them were found on the tape with Methafos, Water Control and the Untreated control.

At the final assessment (48 h), no TPP were found alive with MAVERICK AQUAFLO, Karate Zeon, Benevia, Methafos or Sparta (Figure 3; Figure 5). The percentages of TPP alive, dead and moribund all varied between products ($p<0.001$ overall) and with TPP life stage ($p<0.001$; $p<0.001$; $p=0.045$ for alive, dead and moribund respectively). At 48 h, the percentage found on the tape followed similar patterns to those seen at 19 h (Appendix C).

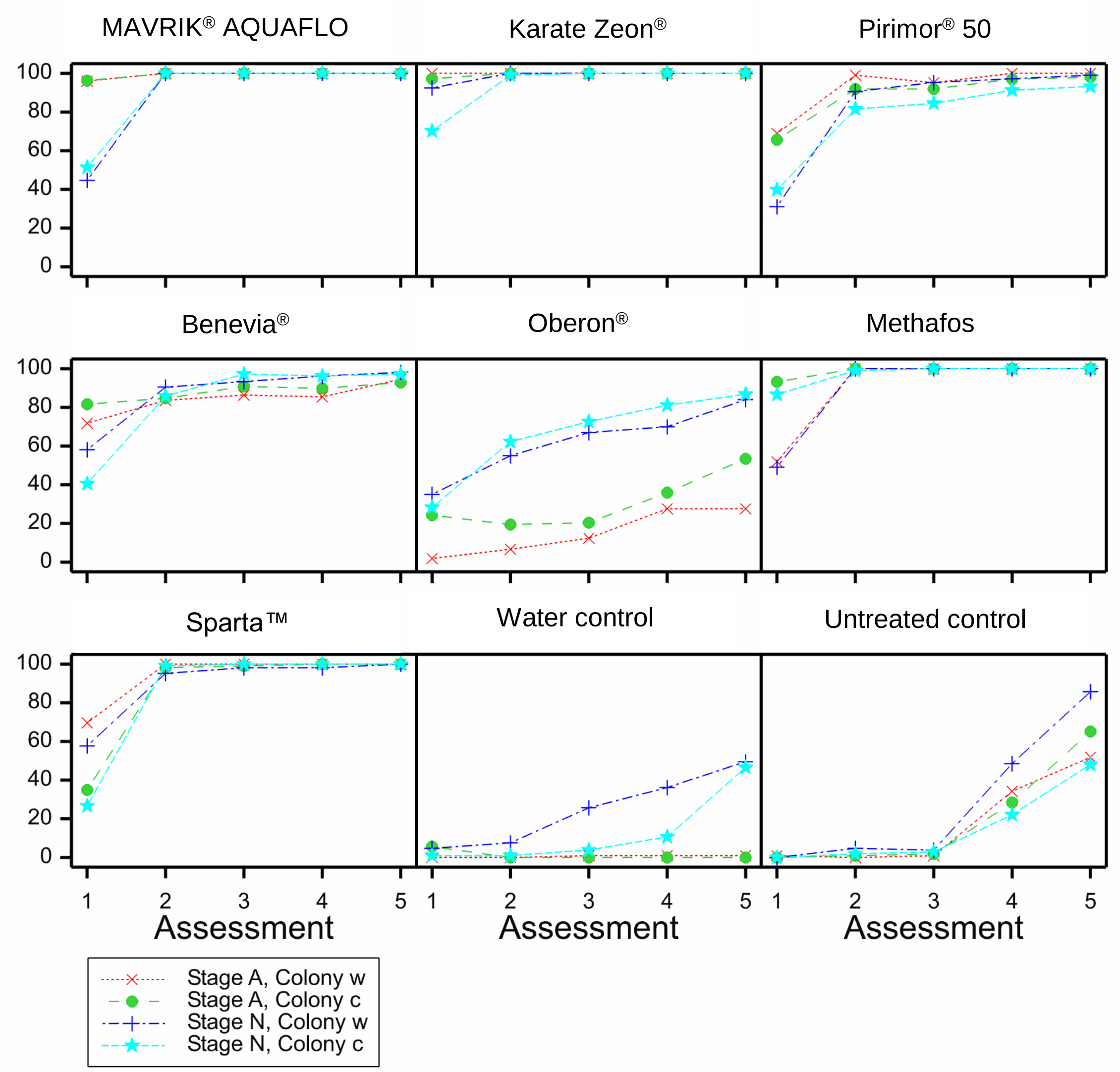

Figure 3. Percentages of dead tomato potato psyllids at each assessment time for each product, Stage = life stage (A = adult, N = nymph) and colony (w = wild colony, c = control PFR lab colony). Assessment times: 1 = 2 h, 2 = 19 h, 3 = 25 h, 4 = 43 h, and 5 = 48 h after applying the products.

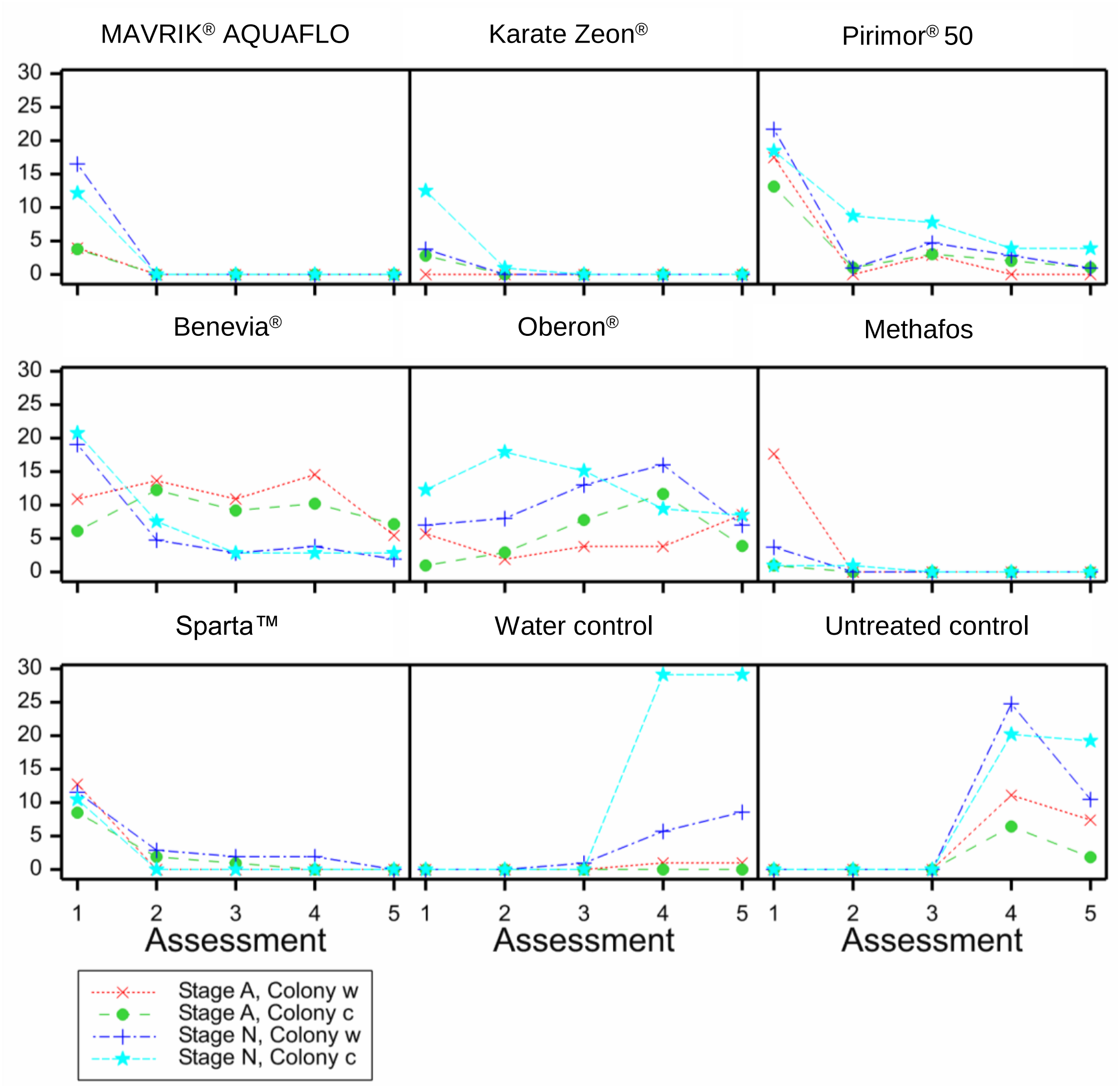

Figure 4. Percentages of moribund tomato potato psyllids at each assessment time for each product, Stage = life stage (A = adult, N = nymph) and colony (w = wild colony, c = control PFR lab colony). Assessment times: 1 = 2 h, 2 = 19 h, 3 = 25 h, 4 = 43 h, and 5 = 48 h after applying the products.

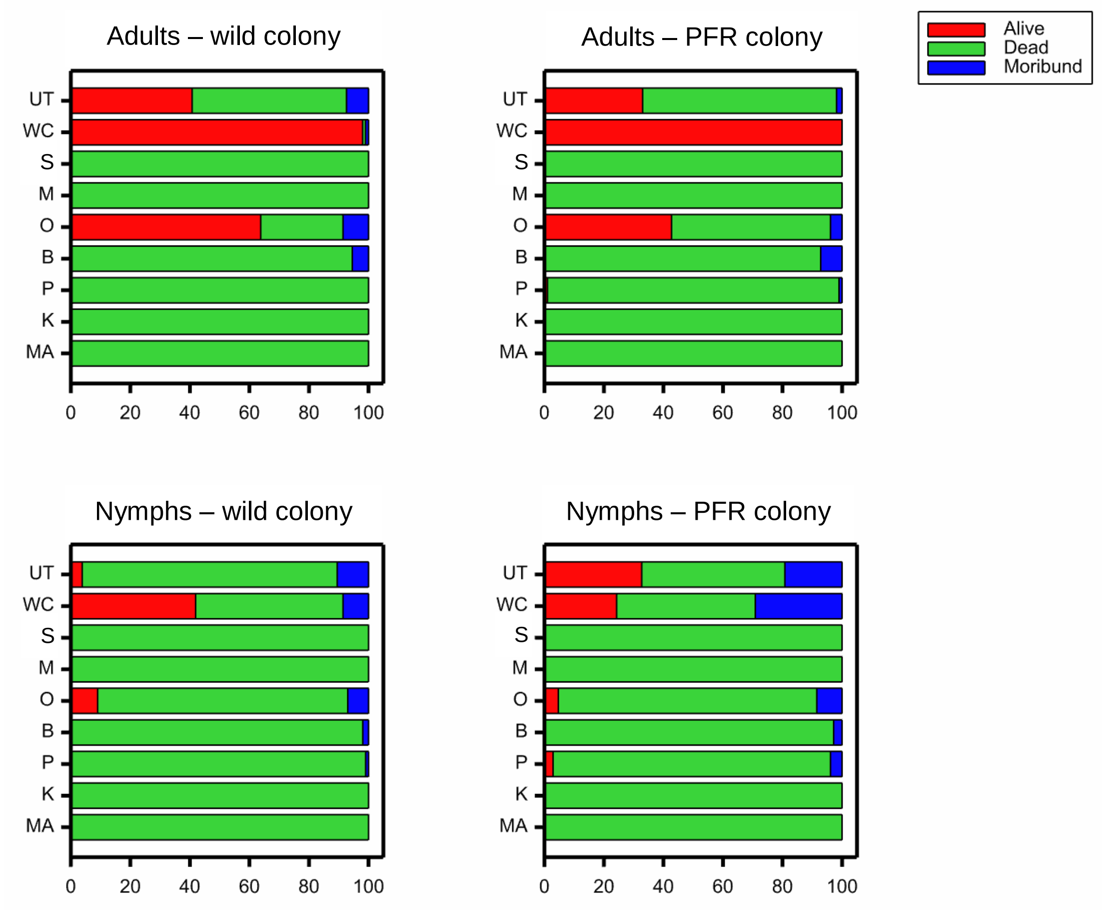

Figure 5. Stacked bar chart of the percentages of tomato potato psyllid adults and nymphs of the wild colony and PFR colony that were alive, dead or moribund for each product at 48 h after applying the products.
MA = MAVRIK® AQUAFLO; K = Karate Zeon®; P = Pirimor® 50; B = Benevia®; O = Oberon®; M = Methafos 600; S = Sparta™; WC = Water control; UT = Untreated (no spray) control.

4 Discussion

The results from this contact insecticide trial showed no material difference in mortality of adults and nymphs between the 'wild' field-collected colony and the susceptible PFR TPP colony for all products tested. Therefore, the perceived lack of control of TPP in Canterbury may have been due to other factors.

Some short notes on two of the products tested:

- Oberon stood out with lower mortality rates for both life stages and a relatively higher percentage of moribund individuals (Figure 3; Figure 4). Oberon induced the lowest mortality in nymphs (84–86.8%) and adults (27.6–53.4%; Appendix C) for both TPP colonies compared with the other contact insecticides tested. In the Oberon FAQs (Bayer, 2021) it states: "Performance evaluations should be made 4 to 10 days following application." The timeframe of our trial (48 h) may explain this lower observed mortality of nymphs and adults compared with the other products. The indirect effects of Oberon on females (reducing fecundity) and viability of eggs (Appendix A) were not measured in this trial.
- The label of Sparta states: "Exposed pests stop feeding immediately but can take up to three days to die". In our trial, mortality of nymphs and adults close to 100% was achieved by 19 h.

A follow-up trial testing systemic and translaminar insecticides currently used to manage TPP in potato crops will be conducted in early 2022, using the same two TPP colonies.

5 Acknowledgements

Thank you to Syngenta Crop Protection Limited, Corteva Agriscience New Zealand Limited, and Seed & Field Services Limited, for providing the products and the Canterbury Potato Liberibacter Initiative (CPLI) for funding this trial.

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Appendix A. Supplementary information on insecticide products used in the trial

Information on the seven contact insecticides tested on tomato potato psyllid adults and fourth-fifth instar nymphs in plastic containers inside a controlled environment room

Insecticide	Active ingredient	Mode of action and IRAC[1] group	Primary site of action	Insecticide properties as per label (unless stated)	Application rate used in trial	Notes/"Product label notes"
MAVRIK® AQUAFLO	Tau-fluvalinate (240 g/L)	Pyrethroids (3A)	Keeps sodium channels open, causing hyperexcitation and, in some cases, nerve block.	Contact	0.4 L/ha	750 mL/ha on label. Client has advised to use 0.4 L/ha. "… potent, broad spectrum, synthetic pyrethroid insecticide with contact action …"
Karate Zeon®	Lambda-cyhalothrin (250 g/L)	Pyrethroids (3A)	Keeps sodium channels open, causing hyperexcitation and, in some cases, nerve block.	Contact	0.1 L/ha	Contact, ingestion, anti-feeding, repellent[3]
Pirimor® 50	Pirimicarb (500 g/kg)	Carbamate (1A)	Inhibits AChE, causing hyperexcitation.	Contact, partially systemic, translaminar[2]	0.5 L/ha	Has a vapour phase, not on EPA[2] list Contact, ingestion, fumigant (>15°C), translaminar[3]
Benevia®	Cyantraniliprole (100 g/L)	Anthranilic diamide (28)	Muscle contraction and paralysis.	Contact, translaminar, systemic	0.5 L/ha	"Benevia® insecticide enters larvae primarily by ingestion, but also by contact. Exposure of the pest species typically results in rapid feeding cessation within a few hours of exposure, however the time to death may take 3 to 6 days, depending upon the species."[4]
Oberon®	Spiromesifen (240 g/L)	Tetronic and Tetramic acid derivatives (23)	Inhibits acetyl coenzyme A carboxylase.	Contact,translaminar, systemic[5]	0.6 L/ha	"Soon after exposure, immatures are trapped in the quiescent stage (cannot progress into the next development stage), and death usually occurs shortly thereafter. Reductions in egg deposition, as well as other symptoms, are observed quickly in adult females following exposure. Transovarial effects will reduce the hatch of eggs that are deposited. Performance evaluations should be made 4 to 10 days following application."[6]
Methafos 600	Methamidophos (600 g/L)	Organophosphate (1B)	Inhibits AChE, causing hyperexcitation.	Contact, translaminar, systemic	1 L/ha	
Sparta™	Spinetoram (120 g/L)	Spinosyn (5)	Allosterically activates nAChRs, causing hyperexcitation of the nervous system.	Contact, limited systemic activity	0.5 L/ha	"… works by both contact and ingestion activity. Exposed larvae stop feeding immediately but can take up to 3 days to die."

[1] IRAC: Insecticide Resistance Action Committee
[2] EPA: Environmental Protection Agency
[3] Additional non-label information for Karate and Pirimor: "Technote" forage and brassica (Syngenta 2021)
[4] Additional non-label information for Benevia: The persistence of the product is from 5 to 14 days, varying depending on the dose and the environment and culture conditions (Nexles® EU 2021). Geoff Cornwell (FMC) by email "Benevia® is the most potent on nymphs but does have some activity on adults – particularly in reducing feeding."
[5] Additional non-label information for Oberon: Product bulletin (Bayer 2020)
[6] Additional non-label information for Oberon: FAQs on website (Bayer 2021)

Appendix B. Label specifications for each insecticide product used in the trial

Insecticide	Specified label for potatoes	Specified label for capsicum	Specified label for potato psyllid (TPP) on potatoes	Label rate for TPP on potatoes	Application rate used in trial
MAVRIK® AQUAFLO	Yes	No	Yes	0.75 L/ha	0.4 L/ha
Karate® Zeon	Yes	No	Yes	0.1 L/ha	0.1 L/ha
Pirimor® 50	Yes	No	No	0.5 L/ha*	0.5 L/ha
Benevia®	Yes	No	Yes	0.5 L/ha	0.5 L/ha
Oberon®	Yes	Yes	Yes	0.6 L/ha	0.6 L/ha
Methafos 600	Yes	No	Yes	1 L/ha	1 L/ha
Sparta™	Yes	No	Yes	0.375–0.5 L/ha	0.5 L/ha

*Recommended Pirimor® 50 label rate for aphids on potato.

Appendix C. Summary of assessments

Percentages of tomato potato psyllid (TPP) that were alive, dead or moribund at 19 h after applying the products, for each product, for each TPP life stage and each colony (95% confidence limits). Please refer to Table 1 for product treatment abbreviations.

Variable	Product	Adult		Nymph	
		Wild colony	PFR colony	Wild colony	PFR colony
Alive	MA	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)
	K	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)
	P	1.0 (0.1,13.8)	7.1 (2.5,18.5)	8.5 (3.4,19.7)	9.7 (4.1,21.4)
	B	2.7 (0.5,12.5)	3.1 (0.6,13.9)	4.8 (1.4,15.2)	6.6 (2.3,17.4)
	O	91.4 (80.2,96.6)	7.7 (64.3,87.0)	37.0 (24.8,51.1)	19.8 (11.1,32.7)
	M	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)
	S	0.0 (0.0,*)	0.0 (0.0,*)	1.9 (0.3,12.5)	1.0 (0.1,13.6)
	WC	100.0 (*,100.0)	100.0 (*,100.0)	92.4 (81.3,97.1)	99.0 (86.2,99.9)
	UT	100.0 (*,100.0)	99.1 (86.8,99.9)	95.2 (84.8,98.6)	98.1 (87.5,99.7)
Dead	MA	100.0 (*,100.0)	100.0 (*,100.0)	100.0 (*,100.0)	100.0 (*,100.0)
	K	100.0 (*,100.0)	100.0 (*,100.0)	100.0 (*,100.0)	99.0 (82.2,100.0)
	P	99.0 (82.0,100.0)	91.9 (78.4,97.3)	90.6 (77.5,96.4)	81.6 (66.8,90.6)
	B	83.6 (69.7,91.9)	84.7 (69.9,92.9)	90.5 (77.3,96.4)	85.8 (71.9,93.5)
	O	6.7 (2.1,19.3)	19.4 (10.0,34.2)	55.0 (39.6,69.5)	62.3 (47.0,75.4)
	M	100.0 (*,100.0)	100.0 (*,100.0)	100.0 (*,100.0)	99.0 (82.3,100.0)
	S	100.0 (*,100.0)	98.1 (85.1,99.8)	95.2 (82.8,98.8)	99.0 (82.3,100.0)
	WC	0.0 (0.0,*)	0.0 (0.0,*)	7.6 (2.6,20.4)	1.0 (0.0,18.0)
	UT	0.0 (0.0,*)	0.9 (0.0,17.1)	4.8 (1.2,17.1)	1.9 (0.2,15.1)
Moribund	MA	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)
	K	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)	1.0 (0.1,7.5)
	P	0.0 (0.0,*)	1.0 (0.1,7.8)	0.9 (0.1,7.3)	8.7 (4.4,16.6)
	B	13.6 (8.1,22.1)	2.2 (6.8,21.1)	4.8 (1.9,11.6)	7.5 (3.6,15.0)
	O	1.9 (0.4,8.0)	2.9 (0.9,9.3)	8.0 (3.8,15.9)	17.9 (11.4,27.1)
	M	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)	1.0 (0.1,7.4)
	S	0.0 (0.0,*)	1.9 (0.4,8.0)	2.9 (0.9,9.3)	0.0 (0.0,*)
	WC	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)
	UT	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)
On Tape	MA	1.0 (0.1,11.5)	1.9 (0.3,10.6)	0.0 (0.0,*)	0.0 (0.0,*)
	K	1.9 (0.3,10.8)	3.7 (1.0,12.5)	1.9 (0.3,10.6)	3.8 (1.1,12.8)
	P	0.0 (0.0,*)	0.0 (0.0,*)	14.2 (7.5,25.1)	2.9 (0.7,11.8)
	B	2.7 (0.6,11.1)	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)
	O	0.0 (0.0,*)	1.0 (0.1,11.3)	20.0 (11.7,32.1)	21.7 (13.2,33.6)
	M	6.9 (2.6,16.7)	1.0 (0.1,11.3)	1.9 (0.3,10.5)	2.9 (0.7,11.6)
	S	0.0 (0.0,*)	2.8 (0.6,11.5)	1.9 (0.3,10.8)	3.8 (1.1,12.7)
	WC	8.9 (3.9,19.3)	5.7 (2.0,14.9)	1.9 (0.3,10.7)	22.3 (13.6,34.5)
	UT	11.1 (5.4,21.5)	0.0 (0.0,*)	1.0 (0.1,11.1)	0.0 (0.0,*)

Percentages of tomato potato psyllid (TPP) that were alive, dead or moribund at 48 h after applying the products, for each product, for each TPP life stage and each colony (95% confidence limits). Please refer to Table 1 for product treatment abbreviations.

Variable	Product	Adult		Nymph	
		Wild colony	PFR colony	Wild colony	PFR colony
Alive	MA	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)
	K	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)
	P	0.0 (0.0,*)	1.0 (0.0,29.3)	0.0 (0.0,*)	2.9 (0.3,20.6)
	B	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)
	O	63.8 (45.5,78.8)	42.7 (26.4,60.8)	9.0 (2.7,26.4)	4.7 (0.9,21.1)
	M	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)
	S	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)
	WC	98.0 (78.1,99.9)	100.0 (*,100.0)	41.9 (25.8,59.9)	24.3 (12.1,42.8)
	UT	40.7 (25.0,58.6)	33.0 (18.9,51.1)	3.8 (0.6,20.6)	32.7 (18.4,51.2)
Dead	MA	100.0 (*,100.0)	100.0 (*,100.0)	100.0 (*,100.0)	100.0 (*,100.0)
	K	100.0 (*,100.0)	100.0 (*,100.0)	100.0 (*,100.0)	100.0 (*,100.0)
	P	100.0 (*,100.0)	98.0 (75.0,99.9)	99.1 (67.6,100.0)	93.2 (74.9,98.4)
	B	94.5 (77.1,98.9)	92.9 (73.8,98.4)	98.1 (76.1,99.9)	97.2 (77.8,99.7)
	O	27.6 (14.0,47.2)	53.4 (34.7,71.2)	84.0 (64.4,93.8)	86.8 (68.2,95.3)
	M	100.0 (*,100.0)	100.0 (*,100.0)	100.0 (*,100.0)	100.0 (*,100.0)
	S	100.0 (*,100.0)	100.0 (*,100.0)	100.0 (*,100.0)	100.0 (*,100.0)
	WC	1.0 (0.0,33.5)	0.0 (0.0,*)	49.5 (31.4,67.7)	46.6 (28.8,65.3)
	UT	51.9 (33.7,69.5)	65.1 (46.0,80.4)	85.7 (66.9,94.7)	48.1 (30.1,66.6)
Moribund	MA	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)
	K	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)
	P	0.0 (0.0,*)	1.0 (0.1,11.1)	0.9 (0.1,10.4)	3.9 (1.1,12.6)
	B	5.5 (2.0,14.1)	7.1 (2.8,17.0)	1.9 (0.3,10.3)	2.8 (0.7,11.1)
	O	8.6 (3.8,18.3)	3.9 (1.1,12.6)	7.0 (2.8,16.7)	8.5 (3.7,18.1)
	M	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)
	S	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)
	WC	1.0 (0.1,10.9)	0.0 (0.0,*)	8.6 (3.8,18.3)	29.1 (19.3,41.4)
	UT	7.4 (3.1,16.7)	1.8 (0.3,10.0)	10.5 (5.0,20.6)	19.2 (11.4,30.7)
On Tape	MA	1.0 (0.0,22.9)	1.9 (0.2,17.6)	0.0 (0.0,*)	0.0 (0.0,*)
	K	1.9 (0.2,17.9)	3.7 (0.7,17.8)	1.9 (0.2,17.6)	3.8 (0.7,18.3)
	P	1.0 (0.0,22.6)	0.0 (0.0,*)	14.2 (6.0,29.7)	3.9 (0.7,18.4)
	B	2.7 (0.4,16.8)	0.0 (0.0,*)	0.0 (0.0,*)	0.0 (0.0,*)
	O	13.3 (5.5,28.9)	3.9 (0.7,18.4)	25.0 (13.3,42.1)	28.3 (16.0,45.0)
	M	6.9 (1.9,21.7)	1.0 (0.0,22.6)	1.9 (0.2,17.4)	2.9 (0.4,17.5)
	S	0.0 (0.0,*)	2.8 (0.4,17.4)	2.9 (0.4,17.7)	3.8 (0.7,18.1)
	WC	32.7 (19.2,49.8)	5.7 (1.4,19.9)	17.1 (7.9,33.2)	37.9 (23.5,54.8)
	UT	18.5 (9.0,34.4)	11.0 (4.2,25.8)	1.0 (0.0,22.2)	1.9 (0.2,17.9)

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