Biorational insecticides for control of the tomato potato psyllid

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Abstract Since its discovery in 2006, the tomato potato psyllid, *Bactericera cockerelli* (Šulc) (TPP), has been considered a significant pest of solanaceous crops in New Zealand, resulting in an intensification of insect pest control measures, often with the use of broad-spectrum insecticides. In the search for more sustainable control methods in outdoor potato crops, several biorational insecticides were tested in laboratory bioassays to assess their effects on TPP behaviour and mortality. The products tested were Organic JMS Stylet-Oil®, Excel Oil®, Eco-Oil®, Neem 600 WP and Sap Sucker Plus. Given the efficacy of JMS Stylet-Oil®, Sap Sucker Plus and Excel Oil® at reducing TPP numbers and their probing/feeding deterrent qualities, these products are now being tested in a field trial. The impacts of the tested biorational insecticides on beneficial insects are also being assessed in laboratory and field trials.

Keywords tomato potato psyllid, biorational insecticide, behaviour, mortality.

INTRODUCTION

Since the tomato potato psyllid, *Bactericera cockerelli* (Šulc) (TPP), was first recorded in New Zealand in 2006 it has caused problems for the capsicum, tomato, potato and tamarillo industries. TPP has led to a considerable increase in insecticide applications in the horticultural industry and thus presents a serious challenge to the implementation of Integrated Pest Management (IPM) strategies (Teulon et al. 2009). TPP vectors the bacterial pathogen *Candidatus Liberibacter solanacearum* (Lso), which is associated with ‘zebra chip’ disease in potato (Munyanza et al. 2007; Liefting et al. 2009). The economic impact of TPP and Lso in New Zealand has been estimated to be millions of dollars in terms of increased management costs, crop losses and loss of export markets (Teulon et al. 2009).

Current TPP pest management practices in New Zealand potato crops rely on very regular applications of often broad-spectrum insecticides. These practices are not only costly but are likely to have a negative impact on the environment and non-target organisms, while increasing the potential for insecticide resistance in pest populations. As part of a sustainable IPM approach, the use of selective, cost-effective and environmentally sensitive products is therefore preferred. Biorational insecticides fit this description and are described “as any type of insecticide active against pest populations, but relatively innocuous to non-target organisms, and, therefore, non-disruptive to biological control” (Stansly et al. 1996). Traditionally soaps/detergents, oils and botanicals have been termed

biorational. These insecticides may affect life stages of psyllid species by direct mortality, or by repellence of adults, deterrence from settling, feeding and/or ovipositing (Al-Jabr 1999; Berry et al. 2009; Marčić et al. 2009; Yang et al. 2010; Boina et al. 2011; Tiwari et al. 2012; Prager et al. 2013). A number of biorational options are already on the market in New Zealand, but to date they have mainly been considered for use in control of TPP on greenhouse crops (Walker et al. 2010; Walker et al. 2011).

Berry & Bourhill's (2012) review of biorational options identified a range of products with potential to control TPP in New Zealand potato crops. Based on this review and industry consultation, five such insecticides were chosen for the research reported here. The objective of this study was to carry out bioassays on potato plants to determine the effects of biorational insecticides on TPP adult behaviour and TPP adult, egg and early-instar mortality.

MATERIALS AND METHODS

Insect source and rearing

TPP adults were obtained from an Lso-positive laboratory colony at Plant & Food Research, Lincoln. TPP were reared on tomato plants ('Moneymaker') in a controlled temperature growth room at 25°C, 40% humidity, 16:8 h light:dark (L:D). Only female TPP were used for the behaviour bioassay, as these are mostly responsible for population growth and so changes in their behaviour are more likely to affect population build-up in a crop. A mixture of male and female TPP was used for the mortality bioassay.

Plant material and application of treatments

In vitro tissue culture plantlets ('Russet Burbank') were planted into individual pots containing potting mix and allowed to grow to the 8-12 leaf stage (approximately 6 weeks) in a controlled temperature growth room (22°C, 50% humidity, 16:8 h L:D) before being used in the bioassays. Five biorational insecticides were used for the bioassays (Table 1) and a water control was also included. These six treatments were applied with a spray bottle.

Ten potato plants were used for each treatment. Four of the 10 plants were used for the behaviour bioassay, which was carried out 24 h after treatments had been applied to selected individual lateral leaflets. The remaining six plants were used for the mortality bioassay, where all six treatments were applied as direct sprays to the whole plants, followed by a second application of all treatments applied to three of the six plants 10 days after the first spray application.

Behaviour bioassay

Bioassays to assess adult female TPP behaviour responses to the treatments were carried out on excised potato leaflets. The main arena described by Liu & Trumble (2004) was modified using a 9 cm plastic Petri dish lined with a moistened filter paper. Immediately prior to the behaviour assessment, the treated leaflet was excised and placed on top of the filter paper with the underside of the leaf facing up. The female TPP was taken from the holding Petri dish, placed on the leaflet in the arena and immediately covered by a 4 cm glass Petri dish. The main arena was then placed under a binocular microscope with cold light for 5 min to allow the female to settle. Behavioural responses were recorded into a digital voice recorder for 15 min. The following categories were used to describe behaviour: resting (R), off leaf (O), walking (W), feeding/probing (F) (indicated by the 45° angle of the insect's body and a wiggling movement), cleaning (C), and jumping (J).

After each assay, the glass Petri dish was rinsed with water, followed by ethanol, and dried with a paper towel before starting another replicate. Each of the six treatments was replicated 12 times, with the order determined by a Latin rectangle. Two assessors ran the bioassays in sequence, with a complete replicate assessed per person per day. Two replicates for each treatment were assessed daily, except for replicates 11 and 12 which were assessed on consecutive days. All bioassays commenced at 10:30 am and a full replicate of six treatments was completed by 2:15 pm.

Table 1 Biorational insecticides used in the tomato potato psyllid behaviour and mortality bioassays.

Trade name	Active ingredient	Mode of action	Formulation	Field rate
Organic JMS Stylet-Oil®	Mineral Oil + adjuvant	Inhibits insect respiration	971 ml/litre EC	1.5 litres/100 litres
Excel Oil®	Mineral Oil	Inhibits insect respiration	843 g/litre EC	1 litre/100 litres
Eco-Oil®	Canola Oil	Inhibits insect respiration	851.5 g/litre EC	7.5 ml/litre
Neem 600 WP	Neem seed kernel extract	Insect growth regulator and antifeedant	600 g/kg neem seed kernel extract	1 kg/100 litres
Sap sucker Plus	Oxygenated monoterpenes, neem oil, dispersants and adjuvants	Antifeedant and insect growth regulator	Information not accessible	240 g in 12 litres water

Mortality bioassay

A bioassay with potato plants was carried out to assess the effect of biorational insecticides and water on TPP mortality. The potted plants were laid out on benches in a controlled environment room at 22°C, 50% humidity and 16:8 h L:D. Pots were laid out using a Latinised resolvable row-column design, constructed with CycDesign Software. Twenty-four hours after the plants had been sprayed with the insecticides or water they were covered with fine mesh cages. Subsequently, 30 TPP adults were released on each plant and then the cage was taped around the base of the pot. Mortality assessments were carried out over a 20-day period (3, 13 and 23 days after release of adult TPP). Three days after release, the total numbers of eggs and live and dead TPP in each cage were counted. All adults were removed and the sex identified under a binocular microscope. Thirteen days after release, the number of remaining eggs and live nymphs were counted. On the same day, a second application of all six treatments was applied to three of the six potato plants per treatment and the TPP life stages present were left to develop and feed on these plants. Thus, in contrast to the indirect first spray, this second one was a direct spray on TPP life stages present at that time. Twenty-three days after release, the number of live and dead nymphs (large, medium and small) and live adults was recorded for each plant.

Statistical analysis

For the behaviour bioassay, the number of behaviour phases for each TPP (e.g. C, O, J, R is four phases), the total number of each behaviour type for each TPP, and the total number of jumps for each TPP in the 15-min period were analysed with a Poisson generalised linear model (GLM) (McCullagh & Nelder 1989), with a log link. The percentage time spent in each phase (excluding jumping) was also analysed to assess whether the proportion of time in each phase out of the total time varied with treatment. This analysis was carried out with a Poisson log-linear model approach for multinomial data (McCullagh & Nelder 1989). The percentage time for each type of behaviour was then analysed individually, as a binomial GLM with a logit link, to provide an assessment of differences between treatments for each behaviour.

For the mortality bioassay, the number of eggs was analysed with a Poisson GLM (McCullagh & Nelder 1989), with a log link. To analyse the number of eggs per female, the total egg counts were analysed with a Poisson GLM with the log(number of females) included as an 'offset', to adjust to eggs per female. The percentage of nymphs in each size category was analysed to assess whether the proportions of nymphs by size out of the total nymphs varied between the treatments. This was done using the Poisson log-linear model for multinomial data.

For all analyses, treatment contrasts were assessed using F-tests within the analyses of deviance, and means and associated 95% confidence limits were obtained on the transformed (link) scale, and back-transformed. All analyses were carried out with GenStat (release 14).

RESULTS

Behaviour bioassay

Of the 71 TPP analysed, 42 began the 15-min period off the leaf and 29 stayed off leaf for 15 minutes, 15 started resting and 2 rested for 15 min, 11 started probing/feeding and 7 probed/fed for 15 min and 3 started walking.

The total number of behavioural phases varied between the treatments, with the highest number found in the water treatment (mean of 7.6 per TPP). Sap Sucker Plus had a significantly lower number of phases (1.6; $P=0.016$) than the water control. Numbers of phases off-leaf did not vary substantially between treatments ($P=0.334$) (Figure 1). There was no TPP feeding observed

on Sap Sucker Plus, which was significantly lower than for water ($P<0.001$). Resting phases were highest with water, significantly more than for either Sap Sucker Plus ($P=0.02$) and Eco-Oil® ($P=0.049$), and slightly higher than for Organic JMS Stylet-Oil® ($P=0.07$). The highest numbers of jump phases were recorded for Organic JMS Stylet-Oil® and Excel Oil® and the lowest for Sap Sucker Plus (Figure 1).

The pattern of percentage time spent on each behaviour varied substantially between the treatments ($P<0.001$) (Figure 2). Egg-laying was observed on one occasion for Neem 600 WP. The percentage of time spent off-leaf increased from around 35% for water to 77% for Organic JMS Stylet-Oil® and 88% for Sap Sucker Plus ($P<0.001$ for the overall difference between treatments). This seems largely to be at the expense of the percentage time spent probing/feeding or cleaning ($P<0.001$ and $P=0.014$ respectively for overall difference between treatments).

Figure 1 Mean number of each behaviour type per tomato potato psyllid, ordered by mean total number of phases. Error bars show 95% confidence limits for the means (omitted when number=0). Different symbols indicate individual treatments: W = water, N = Neem 600WP, X = Excel Oil®, J = Organic JMS Stylet-Oil®, C = Eco-Oil®, S = Sap Sucker Plus.

Figure 2 Percentage time spent on each activity for tomato potato psyllid on each biorational-insecticide or water treated excised leaflet. Note treatments other than water are ordered by the percentage time for off leaf, and activities are ordered by the percentage time over all biorational insecticides for each activity. W = water, N = Neem 600WP, C = Eco-Oil®, X = Excel Oil®, J = Organic JMS Stylet-Oil®, S = Sap Sucker Plus.

Mortality bioassay

Three days after release (one spray applied), total numbers of TPP, numbers of eggs or numbers of eggs laid per female did not vary significantly with treatment ($P > 0.28$).

Thirteen days after release (one spray applied), there was no substantial variation between the treatments in the number of eggs remaining ($P > 0.28$ for all effects). Variation in the number of nymphs on each plant ranged from 0 to 50 per cage and varied strongly with treatment ($P = 0.003$ for the main effect). Nymph numbers were highest for water (mean = 36.5/cage) and lowest for Organic JMS Stylet-Oil® (mean = 2.0/cage; $P = 0.006$).

Twenty-three days after release (two sprays applied), numbers of live nymphs varied with treatment ($P = 0.008$ for the main effect) and number of sprays ($P = 0.004$). However, the

difference between one and two sprays was relatively similar for all treatments ($P = 0.580$). This non-significant interaction means it is not entirely legitimate to make the comparisons between one and two sprays, and therefore further analyses used averages for one and two sprays combined. On average, numbers of nymphs were reduced by the second spray to only a quarter of those found with one spray (Figure 3). However, the reduction in total nymphs compared with water was only significant for Organic JMS Stylet-Oil® and Excel Oil® ($P < 0.001$; $P = 0.035$). Numbers of emerged adults varied between all treatments ($P < 0.001$), but was relatively unaffected by the number of sprays ($P = 0.517$ for the main effect) (Figure 3).

No nymphal stages were found with Organic JMS Stylet-Oil® (Figure 4). The pattern of

Figure 3 Mean total number of tomato potato psyllid nymphs and emerged adults per cage at 23 days after treatment application. Error bars show 95% confidence limits for the highest, a mid range, and a small mean. W = water, J = Organic JMS Stylet-Oil®, X = Excel Oil®, C = Eco-Oil®, N = Neem 600WP, S = Sap Sucker Plus.

Figure 4 Percentage of tomato potato psyllid nymphs that were of each size at 23 days after spray application, averaged over sprays. Note: there were no nymphs for Organic JMS Stylet-Oil, and no nymphs for Sap Sucker Plus with two sprays. W = water, X = Excel Oil®, C = Eco-Oil®, N = Neem 600WP, S = Sap Sucker Plus.

percentages of nymphs across the three class sizes varied quite strongly with treatment ($P < 0.001$) (Figure 4), but was only weakly affected by the number of sprays ($P = 0.910$ for the spray main effect and $P = 0.133$ for the interaction). There was a higher percentage of large nymphs with the water treatment than for the insecticides, with 90% being large for water compared to 22–71% for the insecticides. Eco-Oil® had the highest percentage of small nymphs, and Excel Oil® the highest percentage of medium sized nymphs.

DISCUSSION

Based on the 15-min behaviour bioassay, Sap Sucker Plus and Organic JMS Stylet-Oil® produced the strongest repellent effect to adult female TPP, measured as time off leaf, followed by Excel Oil® and Eco-Oil®. However, on Eco-Oil® a relatively large amount of the time on-leaf was spent feeding/probing (28%) compared with Sap Sucker Plus (0%), Organic JMS Stylet-Oil® (7%) and Excel Oil® (10%). An initial repellent and probing/feeding deterrent effect is important when considering the potential risk of adult TPP settling in a potato crop and transmitting Lso, as a single adult TPP could transmit Lso to a potato plant in as little as 6 h, resulting in the development of zebra chip symptoms (Buchman et al. 2011). Neem 600 WP did not induce a difference in behaviour when compared with water. This is in contrast to the findings of Walker et al (2011), who observed significant repellence

to female adult TPP with Neem, but this was after 1 h and a different Neem formulation was used in the present trial.

In the TPP mortality study, there was no obvious adult mortality or oviposition-deterrent effect for any of the treatments over a 3-day period after the spray application date. However, 13 days after release, nymph numbers were lower for all insecticides when compared with water. The reduction in nymph numbers could suggest that the products have some residual effect on egg hatching rates and/or early instar mortality. Organic JMS Stylet-Oil® and Excel Oil® showed good potential for control of TPP early in the growing season as these had the fewest large nymphs present.

Twenty-three days after release, Eco-Oil® and Neem 600 WP seemed to have lost their effect, as these treatments had a larger number of nymphs compared with the other insecticides. However, the reduction in total nymphs compared with water was only significant for Organic JMS Stylet-Oil® and Excel Oil®. This in contrast to Walker et al. (2010) who reported higher nymphal mortality for Eco-Oil® than for Excel Oil®, which may be due to the direct-only sprays on nymphs they applied. This supports the present results as high nymph numbers (mean=23.1) were observed after the first Eco-Oil® spray (indirect effect) and much lower nymph numbers (mean=1.3) after the second, direct spray. This effect was less pronounced for Excel Oil® (mean=2.7 and

0.3 respectively), which indicates Excel Oil® has more of a residual effect than Eco-Oil®.

Sap Sucker Plus has now been re-formulated into a related product called Thunderbolt. Therefore, future experiments using this product may not give the same results.

Although biorational insecticides have the potential to control TPP through repellency and mortality, there is also a need to consider potential adverse effects of using these products in the cropping system. One potential risk with these insecticides is phytotoxicity. In this experiment some phytotoxicity was noticed on plants sprayed with Excel Oil® and Eco-Oil®, but phytotoxicity was most apparent on Neem 600 WP treated plants. The other potential risk is that of adverse effects on beneficial insects in the cropping system, as have been reported by others (e.g. Bahlai et al. 2010; Simmons & Abd-Rabou 2011). Most biorational insecticides will not clog spray boom nozzles and can be used in tank mixes with conventional pesticides; however, product labels should be checked for order of mixing and exceptions.

Given the efficacy of Organic JMS Stylet-Oil® and Excel Oil® at reducing TPP numbers and their probing/feeding deterrent qualities, these two products warranted further testing in field trials in 2013. Although Sap Sucker Plus left noticeable residue on the leaves, it was also notable for its high repellence effect in the 15-min behavioural studies and is therefore also being tested in a potato field trial. The impact of the tested biorational insecticides on beneficial insects is being assessed in laboratory trials. Depending on the results of these trials, advice can be given on when in the season to use the tested insecticides to optimise biological control while still controlling TPP effectively.

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