Susceptibility of the European earwig, *Forficula auricularia*, to insecticide residues on apple leaves

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Abstract The European earwig (*Forficula auricularia*) is potentially a predator of a number of insect pests in apple orchards. However, its effectiveness as a natural enemy in apple orchards may be compromised by insecticide sprays. A laboratory bioassay of eight insecticides currently used in Integrated Fruit Production (IFP) apple orchards and one as-yet unregistered product was undertaken to determine their effects on earwigs. Adult earwigs were placed in ventilated containers where they were exposed to insecticide residues on apple leaves and monitored on four occasions over 10 days. Indoxacarb, thiacloprid, spinosad and diazinon caused the greatest mortality to earwigs while carbaryl appeared to be less harmful. Chlorantraniliprole, spirotetramat, emamectin benzoate and methoxyfenozide caused no increased mortality of earwigs compared with the control. Identification and avoidance of harmful insecticides may help to enhance the potential of earwigs as natural enemies in apple orchards.

Keywords *Forficula auricularia*, insecticide residues, mortality, Integrated Fruit Production, natural enemy, apple orchards.

INTRODUCTION

The European earwig (*Forficula auricularia*) is widely distributed in New Zealand and is considered both a pest and a predator. It can feed on soft-fleshed fruit and plant material as well as a wide range of arthropods. It is a significant generalist predator in apple orchards and feeds on eggs and active stages of a wide range of insect pests (Buxton 1974). Its ability to maintain woolly apple aphid populations below economic thresholds in apple orchards has been widely reported (Carroll & Hoyt 1984; Mueller et al. 1988; Blommers 1994; Nicholas et al. 2005). European earwigs can also regulate populations of other orchard pests, such as oystershell and apple

mussel scales (McLeod & Chant 1952), European red mite (Phillips 1981) and some Lepidoptera, including codling moth (Causse 1976).

Earwigs are not common in Integrated Fruit Production (IFP)-managed orchards (P.W. Shaw, unpublished data). The potential for earwigs to contribute significantly as natural enemies for a range of orchard insect pests is dependent on their population density, which may vary with sensitivity to insecticides used in pest management spray programmes. As earwigs are univoltine, potential harmful effects from crop protection spray programmes are likely to influence their population dynamics. Organophosphate and

carbamate insecticides are highly disruptive to earwig orchard populations (Epstein et al. 2000). In contrast, earwig abundance was unaffected when the insect growth regulator insecticides (IGR) tebufenozide and lufenuron were field tested in an IFP-managed orchard in Central Otago (Wearing et al. 1999). However, another IGR insecticide, diflubenzuron, has been reported to reduce earwig abundance and indirectly increase woolly apple aphid levels (Ravensberg 1981). Diflubenzuron has also been reported to cause sub-lethal effects resulting in a reduction in predation efficiency in a range of beneficial insects in orchards, including European earwigs (Solomon et al. 2000).

The effect on earwigs of insecticides currently used in IFP apple orchards in New Zealand needs further study. This paper presents results from a laboratory bioassay to determine the residual effects of registered IFP insecticides and a new candidate insecticide (spirotetramat) on European earwigs.

MATERIALS AND METHODS

As earwigs are nocturnal and seek shelter during the day, most would avoid direct contact with insecticides during application but would be exposed to residues on leaves. Therefore, a laboratory trial to monitor the residual effects of insecticides was undertaken. Nine insecticides and water as a control treatment were sprayed at recommended label rates (Table 1) onto well-separated, tagged apple shoots on previously unsprayed apple trees in the field. Treatments were applied on 18–19 January 2010 (with separate water controls on each day) with a small hand pump pressure sprayer (Yates Plassay® Maxi 2) to achieve an even fine spray cover to the point of run-off (water rate equivalent to ~2000 litres/ha). Care was taken to ensure there was no spray drift onto other sprayed shoots on nearby trees. Treated leaves from each shoot were allowed to dry thoroughly and then leaves were removed from shoots using disposable gloves to prevent cross-contamination. The stems of three individual leaves were inserted directly into moistened floral foam, which was then placed inside a ventilated

clear plastic container (100 mm high × 100 mm diameter). This procedure was repeated for five replicates for each insecticide treatment.

Six adult earwigs, collected previously from an unsprayed abandoned orchard, were placed onto treated leaves in each plastic container so that they were in direct contact with spray residues. The earwigs maintained prolonged contact with the leaves as they provided sheltering sites for the earwigs in the containers. No food was provided in the containers but a small amount of leaf feeding was observed in all containers during the course of the tests. Earwigs in the containers were kept in the laboratory and exposed to natural light during the trial (light:dark of ~15:9 h). Temperature during the experiment was maintained at 20°C. Earwigs were assessed for mortality and sublethal effects on four occasions at 1, 3, 7 and 10 days after treatment (DAT). The floral foam was moistened with distilled water during these examinations to prevent leaves drying out over the assessment period. The condition of earwigs was assessed according to observable behavioural effects on individuals using categories described by Peusens & Gobin (2008) as being either alive (showing normal movement and behaviour), affected (attempting to walk but with reduced co-ordination and jittery behaviour), moribund (on their back, twitching, unable to stand upright) or dead (no movement when prodded). In the analysis, dead or moribund individuals were combined together and affected individuals are presented separately.

Statistical analyses

Sublethal (i.e. 'affected') and mortality data from each assessment time were analysed separately using generalised linear modelling (GLM) with pesticide as a fixed effect and replicate within batch as random effects. The best linear unbiased estimates for the fixed effects and their standard errors were used to estimate the back-transformed percent mortality, and 95% confidence interval, for each insecticide. These were compared with the control following the Schneider-Orelli method (Püntener 1981). Analyses and graphs were undertaken using R 2.10.1 (R Development

Table 1 The active ingredient, trade name, formulation and rates of insecticide treatments used in the trial.

Treatment	Trade name and formulation	Rate (a.i./100 litres)
Applied 18 Jan 2010		
carbaryl	Sevin®Flo 500SC	60 g
methoxyfenozide	Prodigy* 240SC	9 g
indoxacarb	Avaunt® 30 WG	6 g
chlorantraniliprole	Altacor® 350WG	3.15 g
untreated (water)		
Applied 19 Jan 2010		
emamectin benzoate	Proclaim® 50WG	0.1 g
spinosad	Success*Naturalyte* 120SC	4.8 g
thiacloprid	Calypso® 480SC	14.4 g
diazinon	Dew™ 600EW	48 g
spirotetramat	Movento® 100SC	7.2 g
untreated (water)		

Core Team, 2009), and the lme4 package (Bates & Maechler 2009).

RESULTS AND DISCUSSION

Results for 'affected' earwig levels and mortality over time have been presented separately to illustrate the progression from when changes in behaviour were observed to subsequent mortality resulting from exposure to insecticide residues. There were clear treatment effects ($P < 0.001$), and the insecticides screened in the bioassay essentially fell into two groups: those that did not affect earwigs or cause increased mortality compared with the control (chlorantraniliprole, spirotetramat, emamectin benzoate and methoxyfenozide), and those that affected earwigs and caused increased mortality (indoxacarb, thiacloprid, carbaryl, diazinon and spinosad) (Figure 1a & b). The result for diazinon and spinosad were consistent with other studies, which have shown that earwigs are susceptible to organophosphate insecticides including diazinon (Bozik et al. 2002; Maher et al. 2006) and spinosyns (Peusens & Gobin 2008). Carbaryl was slightly less harmful than the other insecticides in this group. Indoxacarb, thiacloprid and spinosad all had a large number (> 20 out of 30) of affected earwigs by the third day after

exposure to residues (Figure 1a) and almost all of these affected earwigs had died by the end of the experiment. Sublethal symptoms of 'affected' earwigs were observed relatively quickly 3 days after exposure to residues and if these symptoms occurred in the field it would compromise their ability to find food and leave them vulnerable to dehydration, reducing their chance of survival.

The susceptibility of earwigs to pesticides is an important factor regulating their abundance in orchards. Earwigs have only one generation per year and therefore the effects of even 'slightly harmful' pesticides may have a large impact on population levels and recovery time (Peusens & Gobin 2008). Juvenile stages of earwigs can be more susceptible than adults to some insecticides (Gobin et al. 2008), therefore knowledge of earwig phenology and avoidance of toxic pesticides when juvenile stages are present may help to minimise harmful effects on earwig populations.

In this experiment earwigs were confined in containers and remained in contact with insecticide residues on the treated leaves during the course of the experiment. As residues would decay more quickly in the field, this bioassay provided a worst-case scenario on the effects of these insecticides. Nevertheless results from this study have helped to identify the sensitivity

Figure 1 The percentage change in (a) earwigs showing affected behaviour (reduced mobility and coordination, jittery behaviour) and (b) mortality (moribund and dead) of earwigs over time for nine insecticide treatments. The changes have been adjusted to be relative to the control according to the Schneider-Orelli method.

of earwigs to insecticides currently used in IFP pipfruit spray programmes. Further trials under more natural field conditions will be necessary to validate the impact of these insecticides on earwigs.

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