Evaluating the efficacy of insecticides to control *Sceliodes cordalis* (Doubleday) (Lepidoptera: Crambidae) in eggplant

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Short title: *Sceliodes cordalis* control in eggplant

Abstract

The efficacy of insecticides in controlling *Sceliodes cordalis*, eggfruit caterpillar, in eggplant was tested in four small plot trials because there has been a very limited range of insecticides available to manage this pest. Weekly applications of bifenthrin, flubendiamide, methoxyfenozide, chlorantraniliprole and spinosad and twice weekly applications of methomyl provided control as measured by a percentage of damaged fruit significantly lower than that in an untreated control. Twice weekly applications of methoxyfenozide, chlorantraniliprole or spinosad were not significantly more effective than weekly applications. *Bacillus thuringiensis kurstaki*, emamectin benzoate, indoxacarb, methomyl and pyridalyl applied weekly were ineffective, with percentages of damaged fruit not significantly different from the untreated control. These trials have identified a number of insecticides that could be used to manage *S. cordalis*, including several that would be compatible with integrated pest management programs in eggplant.

Key words: eggfruit caterpillar, *Solanum melongena*, vegetable.

INTRODUCTION

Eggfruit caterpillar, *Sceliodes cordalis* (Doubleday), is an important pest of eggplant, (*Solanum melongena*) in Australia. Davis (1964) described the habits of this insect: the eggs are usually laid on the calyx and the neonate larvae burrow into the fruit; the larvae feed inside the fruit, emerging when they are mature to pupate nearby. The internal damage caused by the larval feeding makes the fruit unuseable. Fruit with larval exit holes will be rejected at harvest, but fruit with larvae still feeding inside and with no external signs of damage may be picked and are only detected when the larvae emerge later or when the fruit are cut. Brown (2002) reported that from 10% to 58% of fruit collected from unsprayed crops in north Queensland were damaged by *S. cordalis*. It occasionally attacks other solanaceous vegetables such as tomato (*Lycopersicon esculentum*) and capsicum (*Capsicum annuum*), while in New Zealand it is a serious pest of pepino (*Solanum muricatum*) (Galbreath & Clearwater 1983).

Insecticides are used to control *S. cordalis* although the insect's habits, with the larvae protected inside the fruit, make this difficult. Few insecticides are registered for use on eggplant, which is considered a minor crop because of the small areas grown and hence is an insignificant market for insecticides, a similar situation to that of some other vegetable crops (Kay 2007) and grain sorghum, pulses and oilseeds (Murray *et al.* 2005). Currently endosulfan is the only insecticide registered for use against *S. cordalis* on eggplant. There are restrictions on its use and Kay and Brown (1992) showed it was only moderately effective. Spinosad is used under permit on pepinos in Western Australia (APVMA 2008). Martin and Workman (1985) reported that methomyl applied weekly prevented damage to greenhouse pepinos in New Zealand. Kay and Brown (1992) tested a number of insecticides for their efficacy against *S. cordalis* in eggplant in north Queensland and found that weekly applications of esfenvalerate and fluvalinate and twice weekly applications of methomyl were the most effective. These insecticides have not since been registered for use against *S. cordalis* on eggplant and, as they are regarded as disruptive to beneficial insects (Llewellyn 2002; Wilson *et al.* 2005), they are unsuitable for use in integrated pest management programs.

Clearly there is a need for other insecticides to be available for use against *S. cordalis* on eggplant, particularly those that would be minimally disruptive to the integrated pest management of other pests of the crop such as thrips and silverleaf whitefly (*Bemisia tabaci*

(Gennadius) biotype B). This paper reports on trials conducted to evaluate the efficacy of 10 insecticides (Table 1) against *S. cordalis*.

MATERIALS AND METHODS

Four trials were done. Trial 1 was conducted at Ayr Research Station (19º37´S, 147º22´E) from September to November 2006 in a crop of the variety Black Pearl grown using standard agronomic practices, with plants spaced 0.5 m apart in rows 1.5 m apart. The trial used a replicated block design with five replicates and plots of three rows by 7 m. Treatments were applied either weekly or twice weekly (i.e. every 3 and 4 days), and treatments were applied for 3 weeks before the first harvest. A further 4 weeks of sprays were applied before the second harvest.

Trials 2, 3 and 4 were conducted at Bundaberg Research Station (24º52´S, 152º21´E) from April to May 2006, December 2006 to January 2007 and November to December 2007 respectively. In all three trials crops were grown using standard agronomic practices in rows 1.5 m apart, using the variety Shiner at a plant spacing of 0.8 m in Trial 2, and the variety Black Pearl at a plant spacing of 0.5 m in Trials 3 and 4. All trials were randomised block designs with four replicates, with plots of three rows by 7 m in Trials 2 and 3 and three rows by 6 m in Trial 4, with 1 m between plots along each row. Treatments were applied weekly or twice weekly in all three trials. In Trial 2, four weeks of sprays were applied before fruit were harvested. Four weeks of sprays were applied before the first harvest and a further 3 weeks of sprays applied before the second harvest in both Trials 3 and 4.

In all four trials the insecticide treatments were applied in the equivalent of 1000 L of water ha^{-1} using a motorised sprayer fitted with a boom and Albuz brown hollow cone nozzles and operated at 690 kPa. Spraying started when all plants were flowering and small fruit were present on a few plants. At each harvest in each trial all fruit except the very small were picked from the middle 5 m of the centre row of each plot. All harvested fruit were returned to the laboratory, counted and cut into slices to detect the presence of larvae or damage so the percentage of damaged fruit could be determined. For each trial, analyses of variance were performed on the number of fruit and on the percentage of damaged fruit, following inverse sine transformation, for each harvest and for the harvests combined, with means separated with a protected least significant difference test, using GenStat 9.2.

RESULTS

In Trial 1 (Table 2) *S. cordalis* infestation levels were very low at the first harvest. In the second harvest and for the combined data only the spinosad, methomyl (twice weekly) and bifenthrin treatments had a significantly lower (*P<0.05*) percentage of damaged fruit than the untreated control. The percentages of damaged fruit in the indoxacarb, *Bacillus thuringiensis*, emamectin benzoate and methoxyfenozide treatments did not differ significantly (*P>0.05*) from the untreated control.

Fruit were harvested only once in Trial 2 (Table 3). There were no significant differences (*P>0.05*) in the percentage of damaged fruit between the untreated control and the emamectin benzoate, indoxacarb and *B. thuringiensis* treatments, while the spinosad, bifenthrin and methomyl (twice weekly) treatments had a significantly lower (*P<0.05*) percentage of damaged fruit than the untreated control.

In Trial 3 (Table 4) the spinosad, methoxyfenozide, chlorantraniliprole and bifenthrin treatments had a significantly lower (*P<0.05*) percentage of damaged fruit than the untreated control at both harvests and for the combined data. The indoxacarb treatment had less damage than the control at the second harvest but not at the first harvest or for the harvests combined. The percentages of damaged fruit in the pyridalyl, emamectin benzoate and methomyl (weekly) treatments did not differ significantly (*P>0.05*) from the untreated control.

The main aim of Trial 4 was to re-test the most promising insecticides (spinosad, chlorantraniliprole and methoxyfenozide) from the earlier trials and to investigate if increasing the frequency of application improved their efficacy in preventing damage by *S. cordalis*. Flubendiamide also was tested and bifenthrin included as a positive control. All the insecticide treatments except methoxyfenozide had significantly lower (*P<0.05*) percentages of damaged fruit than the control at both harvests and for the harvests combined (Table 5). Methoxyfenozide applied either weekly or twice weekly did not differ significantly (*P>0.05*) from the untreated control at the second and first harvests respectively, but both had significantly lower (*P<0.05*) percentages of damaged fruit than the untreated control for the harvests combined. Increasing the frequency of application of any insecticide did not significantly (*P>0.05*) reduce the percentage of damaged fruit except for chlorantraniliprole in the first harvest.

There were no differences (*P>0.05*) in any trial between treatments in the numbers of fruit harvested except in the second harvest in Trial 1, when very low numbers of fruit were picked.

DISCUSSION

Sceliodes cordalis infestation levels, as indicated by levels in the untreated controls, were low in Trial 1, due to very low levels of infestation at the first harvest, and in Trial 2 but moderate in Trials 3 and 4. Despite these low to moderate levels of infestation, effective insecticides significantly reduced ($P<0.05$) the percentage of fruit damaged compared to the untreated control in each trial. Some damage still occurred. The insect's habits mean that the eggs and neonate larvae are the only stages exposed to insecticides, with larvae protected once they have entered the fruit, making control with insecticides difficult.

Emamectin benzoate, indoxacarb, pyridalyl and *B. thuringiensis* were not effective against *S. cordalis* in these trials, with damage levels not significantly different ($P>0.05$) from the untreated controls. Weekly applications of methomyl were not effective (Trial 3) but twice weekly applications were effective (Trials 1 and 2), consistent with the results of our earlier study (Kay and Brown 1992). Bifenthrin, chlorantraniliprole, spinosad and methoxyfenozide were effective in several trials, while flubendiamide was effective in Trial 4. Increasing the frequency of application from weekly to twice weekly did not significantly ($P>0.05$) improve the efficacy of spinosad, methoxyfenozide or chlorantraniliprole. It would be economically and environmentally wasteful for growers to apply insecticides more frequently than necessary to get effective control, and it could increase the risk of having excessive residues on fruit and possibly increase the risk of the insect developing resistance to the insecticides.

Spinosad is registered for use against *Helicoverpa* spp. on eggplant so its use should effectively control both pests, as both may be present in a crop while it is fruiting. Methoxyfenozide, an insect growth regulator, is reported to be most effective against lepidopterous insects when ingested by the larvae, although it has some topical and ovicidal properties (Carlson *et al.* 2001). Possibly it is effective against *S. cordalis* through topical or ovicidal action as there is little opportunity for it to be ingested by the larvae. The same may be the case for methomyl, which also has ovicidal properties against lepidopterous insects (Waite 1981; Hargreaves and Cooper 1982). The ryanodine receptor modulators flubendiamide and chlorantraniliprole belong to new classes of insecticides, the phthalic acid diamides and anthralic diamides respectively, both of which reportedly are highly effective against lepidopterous pests (Nauen 2006).

Integrated pest management programs dependent on parasitoids and predators are being developed in vegetables, particularly against pests such as *B. tabaci* (Brown 2005; De Barro *et al.* 2006), while trichogrammatid wasps in the genera *Trichogramma* and *Trichogrammatoidea* have been recorded parasitising *S. cordalis* eggs (Kay I, 2007, unpublished data). Bifenthrin and methomyl are regarded as disruptive to beneficial insects (Llewellyn 2002; Wilson *et al.* 2005). However spinosad, methoxyfenozide, flubendiamide and chlorantraniliprole are regarded as selective, with only low to moderate levels of impact on beneficial insects and mites (Carlson *et al.* 2001; Llewellyn 2002; Wilson *et al.* 2005; Ebbinghaus *et al.* 2007) and would be suitable for use against *S. cordalis* in integrated pest management programs on eggplant.

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Table 1 Insecticides used in the trials

Active ingredient	Formulation	Trade name
Bacillus thuringiensis kurstaki Strain HD-1	32000 IU dry flowable	DiPel Forté
Bifenthrin	100 g L^{-1} emulsifiable concentrate	Talstar
Chlorantraniliprole	200 g L^{-1} suspension concentrate	Coragen
Emamectin benzoate	44 g kg^{-1} water dispersible granules	Proclaim
Flubendiamide	480 g L^{-1} suspension concentrate	Belt
Indoxacarb	400 g kg^{-1} (300 g kg^{-1} active S-isomer) water dispersible granules	Avatar
Methomyl	225 g L^{-1} emulsifiable concentrate	Lannate L
Methoxyfenozide	240 g L^{-1} suspension concentrate	Prodigy
Pyridalyl	100 g L^{-1} suspension concentrate	Alegro
Spinosad #	120 g L^{-1} suspension concentrate	Success
	240 g L^{-1} suspension concentrate	Success2

The 120 g L^{-1} formulation was used in Trials 2 and 3, and the 240 g L^{-1} formulation was used in Trials 1 and 4.

Table 2 Mean number of fruit harvested and mean percentages of fruit damaged by *S. cordalis* in Trial 1

Treatment (rate ha^{-1})	No. sprays per week	Harvest 1		Harvest 2		Combined	
		No. fruit	% damaged #	No. fruit	% damaged #	No. fruit	% damaged #
Untreated control (-)	-	87.8 a	1.55 a	29.2 abcd	28.24 a	117.0 a	8.10 a
Indoxacarb (75 g a.i. ha^{-1}) †	1	86.8 a	1.87 a	26.0 bcd	21.08 ab	112.8 a	6.82 a
B. thuringiensis kurstaki (1000 g product ha^{-1})	2	85.6 a	2.45 a	40.4 a	15.92 ab	126.0 a	6.32 ab
Emamectin benzoate (11 g a.i. ha^{-1})	1	85.2 a	1.36 a	29.2 abcd	16.93 ab	114.4 a	5.41 ab
Methoxyfenozide (408 g a.i. ha^{-1})	1	96.0 a	0.83 a	36.6 abc	14.75 ab	132.6 a	4.91 abc
Spinosad (96 g a.i. ha^{-1})	1	86.4 a	0.55 a	38.2 ab	9.04 bc	124.6 a	3.39 bc
Methomyl (450 g a.i. ha^{-1}) †	2	90.8 a	1.51 a	20.6 d	8.48 bc	111.4 a	3.27 bc
Bifenthrin (60 g a.i. ha^{-1})	1	93.8 a	1.51 a	24.4 cd	2.77 c	118.2 a	2.45 c

Back-transformed means following inverse sine transformation before analysis.

† A non-ionic organic surfactant was added to the indoxacarb and methomyl sprays at 0.025%.

In each column means followed by the same letter are not significantly different (*P>0.05*).

a.i., active ingredient.

Table 3 Mean number of fruit harvested and mean percentages of fruit damaged by *S. cordalis* in Trial 2

Treatment (rate ha^{-1})	No. sprays per week	No. fruit	% damaged #
Untreated control (-)	-	73.2 a	6.29 a
Emamectin benzoate (11 g a.i. ha^{-1})	1	76.5 a	7.32 a
Indoxacarb (75 g a.i. ha^{-1}) †	1	81.5 a	4.90 ab
B. thuringiensis kurstaki (1000 g product ha^{-1})	2	74.2 a	4.37 abc
Spinosad (96 g a.i. ha^{-1})	1	69.0 a	1.30 bc
Bifenthrin (60 g a.i. ha^{-1})	1	73.0 a	1.26 bc
Methomyl (450 g a.i. ha^{-1}) †	2	68.8 a	0.99 c

Back-transformed means following inverse sine transformation before analysis.

† A non-ionic organic surfactant was added to the indoxacarb and methomyl sprays at 0.025%.

In each column means followed by the same letter are not significantly different ($P>0.05$).

a.i., active ingredient.

Table 4 Mean number of fruit harvested and mean percentages of fruit damaged by *S. cordalis* in Trial 3

Treatment (rate ha^{-1})	No. sprays per week	Harvest 1		Harvest 2		Combined	
		No. fruit	% damaged #	No. fruit	% damaged #	No. fruit	% damaged #
Untreated control (-)	-	71.5 a	23.02 a	49.0 a	31.12 a	120.5 a	26.23 a
Pyridalyl (100 g a.i. ha^{-1})	1	74.8 a	24.14 a	51.2 a	24.42 abc	126.0 a	24.87 a
Emamectin benzoate (11 g a.i. ha^{-1})	1	77.5 a	20.64 ab	63.8 a	24.61 ab	141.2 a	22.62 a
Methomyl (450 g a.i. ha^{-1}) †	1	80.5 a	20.15 ab	62.8 a	24.61 ab	143.2 a	22.40 a
Indoxacarb (75 g a.i. ha^{-1}) †	1	75.8 a	23.14 a	45.2 a	16.93 bcd	121.0 a	20.82 a
Spinosad (96 g a.i. ha^{-1})	1	84.0 a	12.77 bc	70.2 a	15.20 bcd	154.2 a	13.86 b
Methoxyfenozide (408 g a.i. ha^{-1})	1	78.2 a	14.11 bc	65.5 a	10.45 d	143.8 a	12.69 b
Chlorantraniliprole (20 g a.i. ha^{-1})	1	85.5 a	8.53 c	59.2 a	14.23 cd	144.8 a	10.86 b
Bifenthrin (60 g a.i. ha^{-1})	1	70.2 a	8.06 c	68.5 a	2.55 e	138.8 a	5.27 c

Back-transformed means following inverse sine transformation before analysis.

† A non-ionic organic surfactant was added to the indoxacarb and methomyl sprays at 0.025%.

In each column means followed by the same letter are not significantly different (*P>0.05*).

a.i., active ingredient.

Table 5 Mean number of fruit harvested and mean percentages of fruit damaged by *S. cordalis* in Trial 4

Treatment (rate ha^{-1})	No. sprays per week	Harvest 1		Harvest 2		Combined	
		No. fruit	% damaged #	No. fruit	% damaged #	No. fruit	% damaged #
Untreated control (-)	-	56.5 a	23.04 a	73.0 a	17.65 a	129.5 a	20.08 a
Methoxyfenozide (408 g a.i. ha^{-1})	1	63.8 a	9.40 bc	71.2 a	10.45 ab	135.0 a	9.88 bc
Methoxyfenozide (408 g a.i. ha^{-1})	2	56.5 a	16.12 ab	80.8 a	8.49 bc	137.2 a	11.66 b
Flubendiamide (72 g a.i. ha^{-1})	1	59.8 a	12.28 bc	78.2 a	5.71 bcd	138.0 a	9.17 bcd
Spinosad (96 g a.i. ha^{-1})	1	56.5 a	10.17 bc	76.2 a	7.24 bcd	132.8 a	8.74 bcd
Spinosad (96 g a.i. ha^{-1})	2	54.0 a	11.39 bc	77.8 a	3.04 cd	131.8 a	6.81 bcde
Chlorantraniliprole (20 g a.i. ha^{-1})	1	62.5 a	8.92 c	74.8 a	4.51 bcd	137.2 a	6.51 cde
Chlorantraniliprole (20 g a.i. ha^{-1})	2	64.0 a	3.24 d	76.2 a	4.37 bcd	140.2 a	3.94 e
Bifenthrin (60 g a.i. ha^{-1})	1	58.5 a	7.19 cd	70.0 a	2.75 d	128.5 a	4.83 de

Back-transformed means following inverse sine transformation before analysis.

In each column means followed by the same letter are not significantly different ($P>0.05$).

a.i., active ingredient.