Evaluation of foliar and seed treatments for control of the cabbage seedpod weevil (Coleoptera: Curculionidae) in canola[1]

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Abstract—Caged assays and field tests were used to evaluate the effectiveness of organophosphorus, pyrethroid, neonicotinoid, and biologically derived insecticides for reducing populations of the cabbage seedpod weevil, *Ceutorhynchus obstrictus* (Marsham), a new pest of canola in Canada. Complete mortality of caged weevils occurred 48 h after treatment with disulfoton, deltamethrin, carbofuran, oxydemeton-methyl, and chlorpyrifos. Under field conditions, using plots or large strips in commercial fields from 1998 to 2001, only deltamethrin and cyhalothrin-lambda (both pyrethroids) consistently reduced weevil densities, even at high population levels. Chlorpyrifos also significantly reduced weevil numbers and damage in some years, but results were variable and efficacy was too low to manage weevils under outbreak densities. Other insecticides such as spinosad provided moderate weevil control and may have a role in weevil management depending on their effect on beneficial insects relative to more efficacious insecticides. Treatment of canola seed with imidacloprid, lindane, or acetamiprid did not reduce weevil damage. Further research is needed to establish economic thresholds for *C. obstrictus* in canola, to assess the effect of insecticides on nontarget natural enemies of canola insect pests, and to assess the potential for integration of chemical agents with biological and cultural control strategies.

Résumé—Des bioessais en cages et des tests sur le terrain nous ont permis d'évaluer l'efficacité d'insecticides organophosphorés, pyréthrinoïdes et néonicotinoïdes, ainsi que des insecticides d'origine biologique, pour la réduction des populations du charançon des siliques de colza, *Ceutorhynchus obstrictus* (Marsham), un nouveau ravageur du canola au Canada. Un traitement au disulfoton, à la deltaméthrine, au carbofuran, à l'oxydéméthon-méthyle ou au chlorpyrifos entraîne une mortalité totale des charançons en cages en 48 h. Dans des parcelles ou des bandes dans des champs commerciaux en conditions naturelles de 1998 à 2001, seules la deltaméthrine et la cyalothrine-lambda (toutes deux des pyréthrinoïdes) réduisent les densités de charançons de façon soutenue, même lorsque les populations sont abondantes. Certaines années, le chlorpyrifos réduit aussi significativement les nombres de charançons et les dommages aux récoltes, mais ses effets sont variables et son efficacité trop faible pour le contrôle des charançons aux densités de niveau épidémique. D'autres insecticides, tels que le spinosad, procurent un niveau de contrôle moyen et peuvent avoir un rôle dans la lutte contre les charançons, tout dépendant de leur impact

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sur les insectes bénéfiques par comparaison à celui d'autres insecticides plus efficaces. Les traitements des graines de canola à l'imidaclopride, au lindane ou à l'acétamipride ne réduisent pas les dommages causés par les charançons. Il faudra faire des recherches supplémentaires pour établir les seuils économiques de densité de *C. obstrictus* dans les cultures de canola, pour évaluer l'impact des insecticides sur les ennemis naturels non ciblés des insectes ravageurs du canola et déterminer la possibilité d'intégrer les agents chimiques à des stratégies impliquant un contrôle biologique et des méthodes particulières de culture.

[Traduit par la Rédaction]

Introduction

The cabbage seedpod weevil, *Ceutorhynchus obstrictus* (Marsham) (Coleoptera: Curculionidae), was first reported infesting commercial fields of canola, *Brassica napus* L. (Brassicaceae), in southern Alberta, Canada, in 1996 (Butts and Byers 1996). This weevil, introduced from Europe, was first reported in North America in the 1930s (Baker 1936) and is a major limiting factor in the production of canola in Idaho, Oregon, Washington, and California (Carlson *et al.* 1951). Surveys conducted in commercial canola fields in Alberta and Saskatchewan during 1997 to 2000 determined that *C. obstrictus* had dispersed rapidly through cropland in Alberta and Saskatchewan and posed a major threat to the profitable production of canola throughout western Canada (Dosdall *et al.* 2002). The weevil has recently also become a pest of canola in eastern Canada, and was found in Quebec in 2000 (Brodeur *et al.* 2001) and Ontario in 2001 (Mason *et al.* 2004).

Ceutorhynchus obstrictus is univoltine and overwinters in the adult stage under leaf litter in woodlots, tree shelters, and field margins (Dmoch 1965). In early spring the adults fly up to several kilometres to feed on buds and flowers of brassicaceous weeds for about 2 weeks before moving to canola, where they lay eggs inside seed pods that are less than 50 mm long (Doucette 1947; Dmoch 1965; Ni *et al.* 1990; Fox and Dosdall 2003). Peak weevil densities occur in canola at flowering (McCaffrey *et al.* 1986; Dosdall and Moisey 2004). During three larval instars, weevils usually consume three to six seeds before chewing an exit hole through the pod and dropping to the ground to pupate in the soil. The period from pod exit to emergence of new-generation adults is approximately 14 days in southern Alberta, and the entire development from egg to adult emergence takes 4–8 weeks (Dosdall and Moisey 2004). The new generation of adults can migrate several kilometres in search of food, comprising any green tissue of late-maturing Brassicaceae, to accumulate fat reserves before migrating to overwintering habitats in early fall (H.A. Cárcamo, unpublished data).

Depending on growing conditions, cabbage seedpod weevils can reduce yield at various stages of canola development. Nevertheless, most economic damage occurs during the larval stages of weevil development (McCaffrey *et al.* 1986; Buntin 1999). Depending on seed size, three to six seeds are consumed per larva (Dmoch 1965), or about 20% of the seeds in each pod (Buntin 1999). Under high weevil densities, two to three larvae can develop in a pod, consuming most of the seeds (Buntin 1999). Indirect losses from larval damage also occur at harvest because infested pods shatter easily. Preliminary studies from Idaho indicate that capture of three to six weevils per sweep warrants control because yield losses in unsprayed plots ranged from 15% to 35% (McCaffrey *et al.* 1986). A similar threshold of three to four weevils per sweep has been set in southern Alberta (Dosdall *et al.* 2001) until results from cage and plot studies, now in progress, are available.

At present, populations of *C. obstrictus* in the United States are controlled to some degree by natural enemies, primarily the parasitic braconid wasp, *Microctonus melanopus* (Ruthe) (Hymenoptera: Braconidae) (Harmon and McCaffrey 1997; Murchie *et al.* 1997). However, application of a broad-spectrum chemical insecticide (methyl parathion) for control of *C. obstrictus* is necessary in the United States for the economical production of canola (Brown *et al.* 1999), as yields can be reduced by as much as 35% in the absence of one or two insecticide applications per season (McCaffrey *et al.* 1986). Seed treatment with imidacloprid has been reported to reduce weevil damage to canola in the state of Washington (Bragg 1999*a*, 1999*b*), but these findings have not been validated under western Canadian growing conditions. While no insecticides were initially registered in Canada for control of cabbage seedpod weevil in canola, cyhalothrin-lambda (Matador®) and deltamethrin (Decis®) have since received registration (Ali 2004).

There are few published reports that compare the efficacy of insecticides from different chemical families against *C. obstrictus* adults (Cárcamo *et al.* 2001). This research was designed to evaluate various insecticides to identify those most effective for reducing populations of this pest in canola in western Canada.

Materials and methods

Two approaches were used to assess insecticidal efficacy for the control of cabbage seedpod weevil in canola: (1) a small-scale test with caged adults in 1998, and (2) larger scale trials in field plots or commercial canola fields from 1998 to 2002.

Tests with caged weevils

Aluminum foil pans (30 cm × 20 cm × 5 cm in height) covered with coarse mesh screens were used to cage 10 adult weevils; there were four replicate cages per treatment. Insecticides were sprayed across the pans outdoors with a shrouded sprayer (Rogers Innovative Inc., Saskatoon, Saskatchewan) pulled by a four-wheel all-terrain vehicle. The products evaluated were imidacloprid, disulfoton, trichlorfon, carbofuran, oxydemeton-methyl, deltamethrin, chlorpyrifos, and spinosad. Insecticide application rates and specific active ingredients (a.i.) are listed in Table 1 and were selected based on registrations for other insect pests or a best judgment. Wettable paper was placed inside the pans in addition to a flowering raceme of *B. napus*.

Field tests

Four field tests were conducted in commercial canola fields or research plots near the city of Lethbridge, Alberta (49°37′N, 112°39′W). Field test 1 was conducted in 1998 at two sites located about 4 km south of Lethbridge. The products evaluated comprised imidacloprid, trichlorfon, oxydemeton-methyl, deltamethrin, chlorpyrifos, and spinosad (Table 1). The test was replicated in two nearby fields (both *B. napus* at growth stages 4.3 to 4.4 of Harper and Berkenkamp 1975) using a randomized complete block design with four replicate plots, each 9 m × 9 m. Insecticides were sprayed on 8 and 9 July 1998 for fields 1 and 2, respectively.

In field test 2, on 29 June 1999, we evaluated various application rates of chlorpyrifos, deltamethrin, and cyhalothrin-lambda (Table 1) in a commercial canola field (*B. napus* at growth stage 4.1) in the same area as field test 1. The experiment consisted of three trials conducted in the same field on the same day. Each trial was laid out as a randomized complete block design with three replicate plots that measured 4.5 m × 15.0 m.

Field test 3, conducted from 1999 to 2001, was located 2 km east of Lethbridge. In 1999, 20 plots (each 10 m × 10 m) were laid out in a randomized complete block design and planted to *B. napus* 'Q2' on 24 May 1999. The following four treatments (for application rates, see Table 1) with five replicates each were randomly allocated to these plots: (1) untreated control, (2) chlorpyrifos, (3) deltamethrin, and (4) cyhalothrin-lambda. Insecticides were applied when most of the stand reached stages 3.3–4.1 on 21 July 1999. A foliar spray with deltamethrin was applied on 3 September 1999 to plots allocated to treatments 2 and 3 so that yield loss caused by a large outbreak of the cabbage seedpod weevil could be quantified at the late pod stage. In 2000 and 2001, field test 3 was expanded to include three additional treatments to evaluate insecticide-coated seed for residual effects on cabbage seedpod weevil larvae; lindane, acetamiprid, and imidacloprid were evaluated (Table 1). Standard agronomic procedures were carried out from 1999 to 2001. *Brassica napus* 'Q2' was seeded at 6.7 kg/ha and foliar insecticides were applied at the early flower stage except that, owing to human error in 2000, chlorpyrifos had to be applied in two batches on the same day at 47.4 g a.i./ha and 432.7 g a.i./ha. All chemical treatments were reapplied at the correct rate on 11 July 2000 because weevils remained above economic thresholds, evidently owing to a reinvasion.

In 2001, plots were seeded on 27 April, but less than 10% of the stand germinated and irrigation was needed to induce germination of the remaining seeds, which resulted in an uneven stand. As in 2000, plots were irrigated at stage 4.2–4.3 because of severe drought. All plots destined for a foliar insecticide spray had the seed treated with lindane (Vitavax RS®) because of extremely high densities of flea beetles (*Phyllotreta* spp.) (Coleoptera: Chrysomelidae) in the preceding 2 years. Despite this preventative

Table 1. Insecticides tested against the cabbage seedpod weevil, *Ceutorhynchus obstrictus*, in southern Alberta.

Product	Formulation	Composition (g/L)	Method	Rates tested (g a.i./ha)	Experiment(s)
Imidacloprid	Admire®	240	Foliar	50, 100	Cage, field test 1
Imidacloprid	Gaucho Platinum®	480	ST	5.68 g a.i. / kg seed	Field test 3
Acetamiprid	Assail ST®	140	ST	5 g a.i. / kg seed	Field test 3
Lindane	Vitavax RS®	93.5	ST	2.09 g a.i. / kg seed	Field test 3
Disulfoton	Di-Syston®	950	Foliar	200, 400	Cage, field test 1
Deltamethrin	Decis 5 EC®	50	Foliar	5, 7.5	Cage, field tests 1–4
Deltamethrin	Decis FLO®	50	Foliar	5, 7.4	Cage, field tests 1–4
Trichlorfon	Dylox®	420	Foliar	200, 400, 1120	Cage, field test 1
Carbofuran	Furadan	480	Foliar	65, 130	Cage
Oxydemeton-methyl	Metasystox-R®	240	Foliar	150, 300	Cage, field test 1
Chlorpyrifos	Lorsban 4E	480	Foliar	180, 360, 420, 480, 576	Cage, field tests 1–4
Spinosad	Spinosad	480	Foliar	60	Cage, field test 1
Cyhalothrin-lambda	Matador EC® E	120	Foliar	10	Field tests 2–4

Note: ST, seed treatment. Canola seeding rates typically range from 4 to 6 kg/ha, hence the amount of active ingredient (a.i.) per hectare will vary accordingly.

measure, flea beetle control still required a foliar spray with deltamethrin (7.5 g a.i./ha) at the seedling stage (22 June 2001). Chlorpyrifos and pyrethroid foliar insecticides were applied on 10 July 2001, when approximately 90% of the stand was at growth stages 3.3 to 4.1 and 10% or less was at growth stage 4.4; few weevils were active by this time, which confounded comparisons between foliar and seed treatments.

In 2002, the efficacy of imidacloprid (Gaucho Platinum®) was tested under more ideal humid conditions in irrigated plots (22–50 m long × 24 m wide) near Vauxhall (50°04′N, 112°07′W). Plots were seeded on 26 April 2002 at 6 kg/ha to *B. napus* 'Ryder', a glyphosate-tolerant variety. Although a foliar insecticide treatment was planned, in addition to the control (Vitavax RS®) and Gaucho Platinum® treatments, no foliar spray was applied because weevil numbers were too low.

Field test 4 was conducted in 2000 at two commercial farms that were part of a study to develop a trap crop to manage the weevil. The first trial was located near the town of Skiff (49°34′N, 111°36′W), about 100 km southeast of Lethbridge. Chlorpyrifos (480 g a.i./ha) was applied to the entire west and east borders (25 m × 1600 m) of *Brassica rapa* L. at growth stage 4.1 on 22 June 2000, and cyhalothrin-lambda (10 g a.i./ha) was applied to the north and south borders (25 m × 1600 m). The second trial was a *B. rapa* crop located about 5 km southwest of the Lethbridge airport (49°36′N, 112°49′W). The same rates of insecticides were applied (25 June 2000), but for this trial cyhalothrin-lambda was applied to the east and west borders (20 m × 400 m each) and chlorpyrifos to the north and south borders (20 m × 200 m each). In both trials, insecticides were applied by the farmer, using tractor-pulled sprayers.

Sampling

For the study using small aluminum foil cages, live and dead weevils were recorded 1, 12, and 48 h after application of the insecticides. All field-plot tests were sampled less than 24 h before and 24 and (or) 48 h after spraying. Sampling consisted of a minimum of 10, 180° walking sweeps with a 38 cm diameter net through each plot or 20 to 80 sweeps, in sets of 10, for the larger plots and strips on farms (test 4). The sweep-net samples were counted in the field or placed into plastic bags, labelled, and stored at –20 °C until they could be processed. All results are presented as number of weevils per 10 sweeps (hereafter referred to as a sample).

For field tests 2 and 3, damage by the cabbage seedpod weevil larvae was determined at the end of the season when canola plants were mature (growth stage 5.4). For field test 2, 25 plants from each replicate plot were cut off at the base, bagged, and labeled, and the number of pods per plant and number of exit holes per plant were counted. All seed from each plant was threshed, cleaned, and weighed. For field test 3 in 1999, weevil damage to canola pods was estimated by randomly selecting 25 plants in each plot and collecting two pods from the bottom half of the main raceme and two from the top half (*i.e.*, 100 pods per plot), similar to other studies (*e.g.*, Murchie *et al.* 1997). For field test 3 in 2000, all the pods from four randomly selected plants in each plot were examined. In 2001 and 2002, 10 plants were selected from each plot to examine the main, middle, and bottom branches to subsample weevil damage, as recommended by Cárcamo *et al.* (2004). The most advanced plants were selected from the Lethbridge plots in 2001 to ensure exposure to weevil oviposition. Yields in this test were estimated by harvesting a 1.5 m × 10 m strip from each plot.

Data analyses

For field tests 1 and 2, percent reductions of weevils in treated plots were calculated using pre- and post-treatment sweep sample numbers corrected for changes in weevil numbers in the control plots using Abbott's formula (Mulla *et al.* 1971). Data were subjected to analysis of variance (ANOVA) using a General Linear Models procedure and Tukey's studentized range test (SAS Institute Inc. 1990) after performing $\log(x + 1)$ transformations on counts of adults in each sample. For field test 3, weevil abundance, pod damage, and yield, where available, were compared using the ANOVA procedure of Statistix 7 (Analytical Software 2000). Barlett's heterogeneity test, performed by this program, was used to ensure that treatment variances were not heterogeneous. For field test 4, the two samples from the borders were averaged and a two-way ANOVA was performed, using Statistix 7, on weevil counts or arcsin-transformed data for weevil population reduction to test for effects of site and chemical.

Table 2. Mean percent reductions of caged adults of *Ceutorhynchus obstrictus* 1, 12, and 48 h after insecticide application, adjusted for changes in *C. obstrictus* populations in control plots using Abbott's formula.

		Mean percent reduction adjusted with Abbott's formula		
Insecticide	Rate (g a.i./ha)	1 h	12 h	48 h
Imidacloprid	100	55	36	95
Imidacloprid	50	33	46	79
Disulfoton	400	0	100	100
Disulfoton	200	0	100	100
Deltamethrin (Decis 5 EC®)	5	55	100	100
Deltamethrin (Decis FLO®)	5	23	87	100
Trichlorfon	400	0	31	67
Trichlorfon	200	0	0	8
Carbofuran	130	33	95	100
Carbofuran	65	10	92	100
Oxydemeton-methyl	300	0	100	100
Oxydemeton-methyl	150	0	97	100
Chlorpyrifos	360	100	100	100
Chlorpyrifos	180	100	100	100
Spinosad	60	0	0	0
Control	0	—	—	—

Results and discussion

Foliar insecticides

In the caged test in 1999 (Table 2), chlorpyrifos had the fastest efficacy, with 100% mortality 1 h after spraying weevils confined in the meshed cages. After 48 h, six of the eight compounds had killed at least 80% of the weevils; the exceptions were trichlorfon, which killed only 67%, and spinosad, which did not differ from the controls, where 2.5% of the weevils died from causes unrelated to insecticides (Table 2). In the field-plot trial replicated at two farms, only deltamethrin reduced populations by 100% in one field; however, at the nearby field, this compound reduced weevils by only 40% (Table 3). The second most effective insecticide in terms of maximum weevil reduction was chlorpyrifos, which killed a maximum of 87% of weevils in one of the fields. Weevil reduction using the other products ranged from 16% for oxydemeton-methyl to 76% for imidacloprid. Most insecticides had lower efficacy in the field test than in the caged test. However, spinosad had higher efficacy in the field, where it reduced weevil abundance by 31% to 51%, compared with only 2.5% mortality in cages.

The higher efficacy of most insecticides in the small cages relative to the field test was expected, since in the small cages spray coverage was complete, as shown by our spray cards. In the field trials, weevils had the opportunity to avoid or reduce chemical contact, which explains the lower efficacy observed. Trichlorfon and spinosad had modest levels of control in the field trials, and the higher application rate required for the former would make it more expensive than other products. Although spinosad has insecticidal activity both by contact and by ingestion, oral activity tends to be higher (Anonymous 1996). In spring canola, *C. obstrictus* adults are most abundant when the crop is in flower (Dosdall and Moisey 2004). Because adult weevils feed actively on canola pollen and buds, in our tests spinosad probably caused mortality following ingestion of sprayed canola tissues.

Field tests 2–4 compared the efficacy of two pyrethroid (deltamethrin and cyholathrin-lambda) and one organophosphorus (chlorpyrifos) insecticide in reducing weevil abundance (Tables 4–7) and damage to canola. In field test 2 (Table 4), conducted in plots at two canola farms near Lethbridge in 1999, deltamethrin and cyhalothrin-lambda reduced

Table 3. Field test 1: mean numbers of *Ceutorhynchus obstrictus* adults per 10 sweep-net samples collected from field plots of *Brassica napus* before treatment and 24 and 48 h after application of insecticides near Lethbridge, Alberta, in 1998.

	Mean no. of adults per sweep			
Product	Pre-treatment	24 h post-treatment	48 h post-treatment	Abbott's adjusted reduction (%)
		Field 1		
Control	4.9*a*	3.9*a*	2.5*a*	—
Imidacloprid	4.0*a*	1.4*ab*	0.5*b*	76
Trichlorfon	4.6*a*	0.8*b*	0.8*ab*	63
Oxydemeton-methyl	5.6*a*	2.9*ab*	0.8*ab*	70
Deltamethrin	4.2*a*	1.1*b*	0.0*b*	100
Chlorpyrifos (420 g a.i./ha)	5.1*a*	0.6*b*	0.8*b*	67
Chlorpyrifos (350 g a.i./ha)	5.5*a*	1.9*ab*	0.4*b*	87
Spinosad	4.0*a*	1.6*ab*	1.0*ab*	51
		Field 2		
Control	6.4*a*	3.3*a*	3.0*a*	—
Imidacloprid	4.8*a*	1.6*ab*	1.9*ab*	16
Trichlorfon	5.1*a*	0.8*b*	0.6*b*	74
Oxydemeton-methyl	4.8*a*	1.6*ab*	1.9*ab*	16
Deltamethrin	4.0*a*	1.1*b*	1.1*ab*	40
Chlorpyrifos (420 g a.i./ha)	4.2*a*	1.4*b*	1.0*ab*	50
Chlorpyrifos (350 g a.i./ha)	4.2*a*	0.8*ab*	0.5*b*	75
Spinosad	3.9*a*	1.0*ab*	1.3*ab*	31

Note: For each field, means within a column that are followed by the same letter do not differ significantly ($P > 0.05$, Tukey's studentized range test).

Table 4. Effect of foliar insecticide application on populations of *Ceutorhynchus obstrictus* (field test 2, 1999), pod damage, and seed yield.

		Percent reduction			
Product	No. of weevils / 10 sweeps 24 h before treatment	24 h after treatment	48 h after treatment	% pod infestation	Seed yield (g / 25 plants)
Cyhalothrin-lambda	37	83	96	27.7*a*	102.5*a*
Deltamethrin	39	81	95	29.3*a*	102.7*a*
Chlorpyrifos (360 g a.i./ha)	46	47	54	35.7*a*	79.9*a*
Chlorpyrifos (480 g a.i./ha)	27	61	79	31.8*a*	97.6*a*
Chlorpyrifos (576 g a.i./ha)	40	71	87	26.1*a*	110.5*a*
Control	38	—	—	40.7*a*	79.4*a*

Note: Data are combined in the analysis for all three field trials conducted near Lethbridge, Alberta, in plots of *Brassica napus*, and are adjusted for changes in *C. obstrictus* populations in control plots using Abbott's formula. Within a column, means followed by the same letter do not differ significantly ($P > 0.05$, Tukey's studentized range test).

weevil populations by 95% and 96%, respectively, whereas the three application rates of chlorpyrifos reduced weevil populations by only 54% to 87%. Similar differences were observed in plots near the Lethbridge Research Centre (Tables 5, 6), particularly in 2000 (Table 6), when only the pyrethroids were able to reduce extremely high weevil numbers (around 300 to 400 per sample) below economic thresholds (30 to 40 per sample), although two spray

Table 5. Effect of foliar insecticide application on populations of *Ceutorhynchus obstrictus* (field test 3, 1999), pod damage, and seed yield.

		Weevil abundance (mean ± SE)							
Early flower treatment	Late pod treament	20 July	3 Aug.	18 Aug.	2 Sept.	7 Sept.	24 Sept.	% pod infestation (mean ± SE)	Seed yield (mean ± SE, g/m²)
Control	None	0.0±0.0*a*	25.6±3.6*a*	92.8±6.2*a*	1068±244*a*	1843±508*a*	31.6±14.4*ab*	14.2±3.1*a*	131.3±4.6*a*
Deltamethrin	Deltamethrin	0.2±0.0*a*	16.6±2.9*a*	65.6±3.3*a*	980±284*a*	23.4±6.14*b*	9.6±2.42*b*	8±2.1*a*	142.9±11*a*
Chlorpyrifos	Deltamethrin	0.6±0.0*a*	21.6±5.9*a*	45.6±4.7*a*	861.6±147*a*	28±6.83*b*	9.8±1.66*b*	7.2±2.4*a*	126.1±12*a*
Cyhalothrin-lambda	None	0.0±0.0*a*	12.4±2.1*a*	93.6±0.9*a*	943.6±169*a*	1760.4±858*a*	50.4±16.5*a*	12.2±1.56*a*	144.9±3.7*a*

Note: Entries for weevil abundance are the average number of cabbage seedpod weevils per 10 sweeps in plots sprayed at early flower (21 July 1999, growth stage 4.1) and late pod (3 September 1999, growth stage 5.3). SE = 1 standard error of the mean of five plots. Within a column, means not sharing a letter are significantly different (ANOVA, LSD test, $P < 0.05$).

Table 6. Effect of foliar insecticide application on populations of *Ceutorhynchus obstrictus* (field test 3, 2000), pod damage, and seed yield.

	Weevil abundance (mean ± SE)							
Treatment	5 July	7 July	12 July	20 July	26 July	10 Aug.	No. of holes / 100 pods (mean ± SE)	Seed yield (mean ± SE, g/m²)
Acetamiprid, on seed	489.0±62.7*a*	—*	—	62.2±16.4*a*	19.2±6.6*a*	193.5±30.5*a*	53.4±6.5*a*	121.8±15.4*a*
Control	331.5±24.6*a*	213.7±91.2*a*	212.8±44.4*a*	59.5±8.1*a*	30.2±7.2*a*	18.2±7.7*bc*	30.4±5.9*bc*	102.8±22.2*a*
Deltamethrin, foliar	399.0±55.0*a*	88.9±6.4*a*	19.8±8.2*b*	66.0±16.1*a*	40.0±8.7*a*	7.2±2.3*a*	17.6±4.2*cd*	141.7±11.2*a*
Imidacloprid, on seed	459.0±53.0*a*	—	—	66.7±23.6*a*	14.5±4.0*a*	228.7±43.0*a*	40.8±7.3*ab*	93.2±3.8*a*
Lindane, on seed	445.5±52.3*a*	—	—	66.0±6.6*a*	22.2±5.6*a*	90.7±34.7*ab*	37.8±2.2*b*	150.4±10.4*a*
Chlorpyrifos, foliar	347.5±37.2*a*	177.3±15.9*a*	96.3±20.0*ab*	62.5±19.4*a*	25.2±7.6*a*	22.0±12.4*bc*	31.3±5.6*bc*	125.0±9.9*a*
Cyhalothrin-lambda, foliar	349.5±51.7*a*	137.7±62.0*a*	30.0±5.6*a*	49.2±17.0*a*	39.0±11.3*a*	14.2±6.6*c*	13.1±1.9*d*	135.4±20.1*a*

Note: Weevil abundance values are the average number of cabbage seedpod weevils per 10 sweeps in plots used for foliar spray (6 and 11 July 2000) and seed treatments near Lethbridge, Alberta. Within a column, means not sharing a letter are significantly different (ANOVA, LSD test, $P < 0.05$).

*Seed-treatment plots were not sampled on all dates.

Table 7. Effect of foliar insecticide application on populations of *Ceutorhynchus obstrictus* at two commercial farms in southern Alberta (field test 4, 2000).

		Average no. of weevils / 10 sweeps (mean ± SE)		
Site	Insecticide	–24 h	+48 h	% reduction (mean ± SE)*
Lethbridge	Chlorpyrifos	325.0±25*a*	120.0±34.5*a*	64.0±7.5*a*
	Cyhalothrin-lambda	600.0±150*a*	69.0±9.5*a*	88.0±1.2*b*
Skiff	Chlorpyrifos	120.5±4.5*a*	44.2±6.2*a*	63.4±3.8*a*
	Cyhalothrin-lambda	94.7±20.5*a*	6.5±5.5*b*	94.1±4.5*b*

Note: At Skiff, cyhalothrin-lambda was applied to the north and south borders of the plot, and chlorpyrifos to the east and west borders; at Lethbridge, the pattern was reversed. For each site, means within a column not sharing the same letter are significantly different (ANOVA, $P < 0.05$).

*Based on weevils found 24 h before spray; values were arcsin-transformed.

applications were needed because of the high numbers or re-immigration. The large-scale farm tests that were part of a trap crop study in 2000 confirmed the higher efficacy of the pyrethroids (88%–94% reduction) over chlorpyrifos (63%–64%) at the two farms (Table 7).

Effects of insecticides on weevil damage to canola, in terms of pod infestations, generally followed the same patterns observed for effects on weevil populations; however, the differences were often not significant. In 2000, in plots under very high weevil pressure (Table 6), only cyhalothrin-lambda reduced damage to infestation levels significantly lower than the control. However, yields did not differ in this trial in 2000 or in any other year despite differences in pod infestations. In the other plot study conducted in 1999 (Table 4, field test 2), yields were higher in most of the sprayed treatments than in the control but did not differ significantly.

Our results, similar to those of other studies, show that pyrethroids provided more effective cabbage seedpod weevil control than other insecticides (Murchie *et al.* 1997; Buntin 1999). Chlorpyrifos, although not registered for cabbage seedpod weevil control, was used in 1999 by some growers probably because it is registered for use in canola against other insects such as lygus bugs (*Lygus* spp.; Hemiptera: Miridae). At high weevil populations, such as those experienced in the Lethbridge area in 2000, this compound could not adequately reduce economically damaging infestations. At the Skiff site, the farmer had to respray cyhalothrin-lambda on areas previously treated with chlorpyrifos to reduce weevil abundance below the nominal threshold of 30 weevils per sample. In the plot trial in field test 3 near Lethbridge in 2000 (Table 5), weevils remained well above economic thresholds (96 per sample) after two sprays of chlorpyrifos at 432 g a.i./ha on 6 July and 480 g a.i./ha on 11 July. Other farmers in the area had experienced similar results with this compound when it was applied at the rate of 480 g a.i./ha recommended for lygus bug control (D. Steele, personal communication with H.A. Cárcamo).

The relatively high numbers of cabbage seedpod weevil exit holes in canola pods following insecticide applications that effectively reduced populations of adults could indicate that the plots were reinvaded from the surrounding canola fields after the applications were made or that the sprays were applied too late in the season, after oviposition had been initiated. In this study, the insecticides were most frequently applied relatively early in flowering (10%–25% flower, stages 4.1 to 4.2) to minimize negative effects on nontarget arthropod species. However, to have the greatest impact, earlier application — at the late bud stage of canola development — may have been preferable. Recent research has shown that numbers of adult weevils in canola at the bud stage of development are nearly as high as those at the early to mid-flowering stages (Dosdall and Moisey 2004). Insecticide application at the bud stage would also minimize harm to nontarget pollinators. In the Pacific Northwest of the United States, canola growers often make two applications of insecticide to optimize control of the cabbage seedpod weevil; the second application is targeted at the new-generation adults that emerge from infested soil and feed on green pods late in the season (McCaffrey *et al.* 1986). However, Buntin *et al.* (1995) showed that feeding by new-generation weevils causes little seed mass yield loss, although seed germination potential is decreased. Our results support their findings, as there was no yield response to late-summer application, even though weevil numbers were extremely high in field test 3. These weevils feed mostly on the small, immature pods that contribute little to yield. Under very high populations of weevils in the spring, it may be necessary to spray early-planted fields twice, but more research is needed to confirm this strategy.

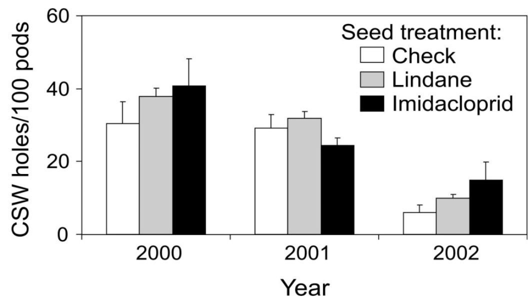
Insecticide-coated seed

Plots planted with imidacloprid-treated canola seed in 2000 had twice as much pod damage from the weevil as those sprayed with the pyrethroid foliar insecticides (<20 *vs.* 40–50 holes per 100 pods; Table 6). In 2001 and 2002, weevil populations were low; however, infestation levels of plots planted with treated seed were not reduced compared with the controls or were even slightly higher (Fig. 1). These results are in contrast with those reported by Bragg (1999*a*, 1999*b*), who found a significant reduction in weevil exit holes in trials conducted in Washington State. We cannot explain the large difference in efficacy between the two studies. Moisture was not a limiting factor at the irrigated Vauxhall site, where even low weevil densities caused slightly higher damage in plots planted with imidacloprid-coated seed than in control plots. The higher damage observed in plots with seed treatments (*e.g.*, plot with acetamiprid-coated seed in 2000 had a weevil emergence rate of 53% *vs.* 30% in the control) can be explained by the earlier flowering relative to untreated plants, which were delayed as a result of flea beetle damage. Neonicotinoid compounds such as imidacloprid effectively prevent flea beetle damage and are registered in Canada (Ali 2004). By reducing flea beetle damage, these chemicals allow plants to grow more vigorously and flower early and, in our study, resulted in plots acting as trap crops for weevils (Buntin 1998; H.A. Cárcamo, unpublished data), which can explain the high numbers of weevil exit holes.

Conclusion

Among the insecticides evaluated, the pyrethroids deltamethrin and cyhalothrin-lambda were generally most consistent and effective under field conditions. Chlorpyrifos was less effective and did not provide sufficient control under high weevil pressure. The seed treatments (lindane, acetamiprid, and imidacloprid) did not protect plants from weevil damage. Although spinosad provided only moderate weevil control, this botanical extract may still have a role under an integrated pest management approach if it has a lesser negative effect on nontarget natural enemies. Further research is required to confirm the necessary timing and frequency of insecticide applications, to develop accurate economic thresholds, and to integrate insecticide technologies with other strategies such as biological control and cultural management using trap crops.

Fig. 1. Comparison of cabbage seedpod weevil (CSW; *Ceutorhynchus obstrictus*) damage (number of exit holes per 100 pods) to plants grown from seed treated with imidacloprid or lindane or grown from untreated seed (check) at Lethbridge, Alberta (2000 and 2001) or Vauxhall, Alberta (2002).



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