Effect of Amitraz on Colorado Potato Beetle (Coleoptera: Chrysomelidae) Feeding, Development and Survival[1]

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ABSTRACT Effects of amitraz, a formamidine insecticide, were studied in Colorado potato beetle, *Leptinotarsa decemlineata* (Say), populations from Minnesota, North Dakota and Virginia. Contact exposure or ingestion of leaves dipped in 4000 ppm amitraz was not lethal to adults. However, adult feeding was reduced 50% upon exposure to 90 ppm amitraz, a rate <1/8 that recommended by the manufacturer for testing as a foliar insecticide. Ingestion of foliage treated with 945 ppm amitraz by early instar larvae had long-term effects on Colorado potato beetle development and survival, delaying adult emergence 4.7 days and causing 87% mortality. In 72 h bioassays, LC_{50}s by contact exposure or ingestion were > 3.2X the suggested field rate. LC_{50}s determined by exposure of larvae to treated foliage were greater than LC_{50}s determined by immersing larvae. Egg hatch was not reduced by application of ≤ 1840 ppm amitraz. In field trials, amitraz reduced defoliation as effectively as esfenvalerate, the insecticide of choice when these trials were conducted. Amitraz-treated plots had yields intermediate between esfenvalerate and control treatments.

KEY WORDS Coleoptera, Chrysomelidae, *Leptinotarsa decemlineata*, Colorado potato beetle, amitraz, Mitac, formamidine

Colorado potato beetle, *Leptinotarsa decemlineata* (Say), is the most destructive defoliating pest of potato, *Solanum tuberosum* L., throughout most of the United States (Radcliffe et al. 1991). In much of the eastern U.S., Colorado potato beetle is resistant to all classes of conventional insecticides (Forgash 1985, Roush et al. 1990). Insecticides with low acute toxicity, but having sublethal effects on feeding, development, reproduction or behavior, may provide an alternative approach to achieving effective pest management of this insect (Haynes 1988). Amitraz represents a novel class of insecticides called formamidines that have ovicidal, lethal, repellent, and behavioral effects on some mites, ticks, and insects (see refs. in Knowles 1982, 1983). Formamidines interact with receptors in the insect nervous system to interfere with octopamine-mediated neurotransmission (Beeman 1982, Orr et al. 1990).

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The objective of this study was to evaluate the effectiveness of amitraz against Colorado potato beetle. Experiments were done using Colorado potato beetle populations from Minnesota, North Dakota, and Virginia. Field trials were conducted in each state, providing direct comparison of the efficacy of amitraz against three populations. Complimentary laboratory trials were done to measure effects of amitraz by contact or by ingestion on egg hatch, larval development and survival, and adult feeding and survival.

Materials and Methods

Laboratory experiments. Colorado potato beetle egg masses and adults were collected from the University of Minnesota Agricultural Experiment Station, Rosemount, MN; the Red River Valley Potato Growers Research Farm, Grand Forks, ND; and the Virginia Polytechnic Institute and State University, Eastern Shore Agricultural Research and Extension Center, Painter, VA. Larvae were obtained from field-collected egg masses. In laboratory tests, amitraz dilutions (Mitac 1.5 Emulsifiable Concentrate; AgrEvo, Wilmington, DE) were prepared in distilled water.

Rates tested are reported here as parts per million (ppm) active ingredient [AI]. Distilled water was used as the control. Although amitraz (Mitac) is not labeled for use on potato, the manufacturer suggested a field rate equivalent to 780 ppm amitraz (0.56 kg [AI] in 739 liters water/ha) for Colorado potato beetle control trials (James Steffel, personal communication).

Adult feeding and mortality. The feeding inhibition effect induced by amitraz on adults (Rosemount population) was evaluated after exposure to potato leaf disks treated with amitraz. Leaf disks (2.1-cm diam) were cut with a cork borer from potato leaves with well-developed primary leaflets; care was taken to avoid the midrib. Area of each leaf disk was measured three times using a digitizing leaf area meter (model LI-3000, Li-Cor, Lincoln, NE), and the average value was recorded. Leaf disks were immersed in treatment solutions for 5 s and allowed to air-dry for 30 min. Control leaf disks were immersed in distilled water. Two adults, prestarved for 12 h, were placed in a 9-cm diam Petri dish with three treated leaf disks (30 to 430 ppm, 1.7X increments). Each treatment, including the control, was replicated eight times. Leaf disks were replaced with newly-treated disks after 24 and 48 h. Thirty leaf disks were immersed in distilled water and left in Petri dishes without insects to correct for leaf shrinkage. Mortality and residual leaf area were determined at 24 and 72 h. In all experiments, moribund insects were considered dead if unable to right themselves within 5 min of being turned on their dorsum.

Mortality of adults induced by ingestion of amitraz was determined after exposure to potato leaflets immersed for 5 s in 0, 750, 1000, 3000, or 4000 ppm amitraz. Three treated leaflets were dried for 5 min and placed in 9-cm Petri dishes containing 10 insects. Each treatment was replicated three (Rosemount population) or four times (Grand Forks population). Treated leaflets were replaced with untreated foliage after 24h. Mortality was determined at 24, 48, and 72 h. Data were not corrected for control mortality in this bioassay or any of the following bioassays because mortality in controls was infrequent.

Mortality of adults induced by contact exposure to amitraz was evaluated by immersing eight or nine beetles for 5 s in 0, 750, 1000, 2000, 3000, or 4000 ppm amitraz. Treatments were replicated two (Rosemount population) or three (Grand Forks population) times. Adults were provided with untreated leaf material. Mortality was determined at 48 h.

Larval development, mortality, and behavior. Effects of amitraz ingestion on development and mortality of early instars was evaluated at 0, 945, 1700, or 3060 ppm. Leaflets were immersed for 5 s and air-dried for 1 h. Within 12 h after eclosion ten first-instars (Rosemount population) per replicate were randomly assigned to treatment levels and placed in a 9-cm Petri dish. Treatments, including a control, were replicated three times. Three treated leaflets were provided on d 1 and d 7, simulating two field applications. Three untreated leaflets were provided on d 4 to 6, and from d 10 until all beetles died or emerged as adults. Development rate was determined by calculating the relative developmental instar (rdi) at 10 d (Zebitz 1984). The relative developmental instar was calculated from the number of live larvae recorded in each stadium according to the following formula: (number of larvae in second stadium $\times$ 2) + (number of larvae in third stadium $\times$ 3) + (number of larvae in fourth stadium $\times$ 4); the sum was divided by the number of live larvae. Cumulative duration and cumulative mortality were determined at the fourth stadium, pupation, and adult emergence. The repellent effect of amitraz was evaluated by determining the percentage of larvae on treated leaflets at 24, 48, and 72 h. Straying larvae were returned to the leaflets after each observation.

The effect on development and mortality induced by contact exposure on 1-day-old third instars (Rosemount population) was evaluated at five concentrations of amitraz ranging from 290 to 3060 ppm. Insecticide was applied to the dorsal abdomen of each larva using a #1 camel's hair brush. Treatment solutions covered the entire insect, therefore, this bioassay was equivalent to immersing larvae. For each treatment, nine larvae were placed in each of three Petri dishes containing untreated potato foliage. Mortality and stadium were determined at 24, 72, and 96 h. Larvae were examined 15 min after treatment for evidence of tetanic spasms.

Determination of contact LC_{50} for larvae. Second and third instars field-collected at Painter, VA were dipped for 5 s in each of six amitraz concentrations (second instars = 80 to 1650 ppm, 1.8X increments; third instars = 920 to 17,290 ppm, 1.5X increments). Larvae were placed on untreated potato leaves inside Dupont rearing trays (Bioserv, Frenchtown, NJ). In tests with second instars, 96 larvae were tested per concentration (24 larvae in each of 4 trays). In tests with third instars, 128 larvae were tested per concentration (16 larvae in each of 8 trays). Mortality was determined at 72 h.

Determination of ingestion LC_{50} for larvae. Potato leaves were immersed for 5 s in each of six amitraz concentrations (1830 to 13,960 ppm, 7.6 X increments) and air-dried. Second and third instars field-collected at Painter, VA were placed on treated potato leaves inside Dupont rearing trays. In tests with second instars, 64 larvae were tested per concentration (16 larvae in each of 4 trays). In tests with third instars, 64 larvae were tested per concentration (16 larvae in each of 4 trays). Mortality was determined at 72 h.

Egg mass dip bioassay. Egg masses were randomly field-collected at Painter, VA, immersed for 5 sec in five amitraz concentrations (175 to 3320 ppm, 1.8X increments), and placed in trays containing potato foliage. We tested 40 egg masses per treatment (10 egg masses in each of four bioassay trays). An egg mass was considered to have hatched if more than 5% of all eggs in a mass hatched.

Field experiments. *Rosemount, MN.* 'Russet Burbank' potatoes were planted 15 May 1991 at the University of Minnesota Agricultural Experiment Station, Rosemount. Seed pieces were planted 0.3 m apart in plots consisting of four rows 11 m long and spaced 1.0 m apart. Plots were separated by 2.0 m of cultivated soil. Treatments were replicated three times in a randomized complete block design. Plots were scouted daily for egg masses beginning 8 June. When egg masses were first observed they were flagged and checked daily for hatch. The first insecticide application was made at the onset of hatch in 30% of the flagged egg masses in each generation. Applications of amitraz (Mitac 1.5 EC) and esfenvalerate (Asana XL 0.66 EC) were made 18 and 24 June (first generation), 23 and 29 July, and 13 August (second generation). Foliar sprays were applied in 739 liters of water/ha (79 gal/acre) at 620 kPa (90 psi) using a tractor-mounted boom sprayer with drop nozzles. Colorado potato beetle larvae were counted on eight randomly chosen whole plants per plot on 21 and 26 June, 25 July and 1, 9, and 15 August. Small larvae included instars I and II; large larvae included instars III and IV. Percentage defoliation by Colorado potato beetle feeding was visually estimated on eight plants per plot eight times between 28 June and 9 August. Numbers of potato leafhopper, *Empoasca fabae* (Harris), nymphs were counted on 35 randomly chosen mid-plant leaves per plot on 30 July and 29 August. Numbers of green peach aphid, *Myzus persicae* (Sulzer) were counted on 35 mid-plant leaves per plot on 29 August.

Grand Forks, ND. 'Red Pontiac' potatoes were planted 14 May 1991 at the Red River Valley Potato Growers Association Research Farm, Grand Forks. Seed pieces were planted 0.3 m apart in plots consisting of four rows 14 m long and spaced 0.96 m apart. Plots were separated by 2.0 m of cultivated soil. Treatments were replicated four times in a randomized complete block design. Egg hatch was monitored as at Rosemount and first insecticide applications were timed at the same threshold. Applications of amitraz (Mitac 1.5 EC) and esfenvalerate (Asana XL 0.66 EC) were made on 19 and 26 June (first generation) and 5 August (second generation). Foliar sprays were applied in 374 liters of water/ha (40 gal/acre) at 275 kPa (40 psi) using a tractor-mounted boom sprayer with a single TeeJet nozzle over each row. Colorado potato beetle larvae were counted on 10 randomly chosen whole plants per plot on 28 June and 10 July. Percentage defoliation by Colorado potato beetle feeding was visually estimated on 10 plants per plot on 28 June, 10 and 25 July, and 9 and 16 August. Numbers of potato leafhopper nymphs were counted on 35 randomly chosen mid-plant leaves per plot on 9 and 16 August.

Painter, VA. 'Superior' potatoes were planted 17 April 1991 at the eastern Shore Agricultural Experiment Station, Painter. Treatments were replicated four times in a randomized complete block design. We evaluated two amitraz treatment schedules: 1) amitraz sprays applied on 13, 20, and 28 May and 4 June, and 2) amitraz sprays applied 28 May (when a heavy infestation of larvae was present) and 4 June. Applications were made with a backpack sprayer using three hollow cone drop nozzles per row. Spray volume was 374 liters of water/ha (40 gal/acre) at 275 kPa (40 psi). Larvae were counted on 10 potato stems per plot on 22 and 31 May, and 6 and 14 June. Percentage defoliation by Colorado potato beetle feeding was visually estimated on 10 stems per plot on 6 June.

Statistical analyses. Data from experiments conducted in Minnesota and North Dakota were analyzed by analysis of variance (ANOVA) using WinSTAR statistical software (WinSTAR, Anderson-Bell Corp., Arvada, California). Means were separated with Scheffe's test. Field-collected data were averaged over all sampling dates for analysis. Insect counts and development time were transformed to $\log_{10}(x + 1)$ values, and mortality and defoliation percentages were transformed to arcsine values before analysis. In Virginia, dose-mortality data were subjected to probit analysis (SAS Institute 1985). The Virginia field experiment was analyzed by ANOVA, and treatment means were compared with Ryan's Q test (SAS Institute 1985). Untransformed values are presented in the tables.

Results and Discussion

Adult feeding and mortality. Adult ingestion of amitraz-treated leaf disks decreased feeding after exposures of 24 and 72 h ($F = 25.12$ and $F = 22.11$, respectively; df = 6, 14; $P < 0.001$) (Fig. 1). The lowest concentration that consistently differed from the control, 50 ppm amitraz, reduced adult feeding 38% at 24 h and 70% at 72 h. The highest rate tested, 430 ppm amitraz, reduced feeding 87% at 24 h and 93% at 72 h. Treatment differences were not significant between 50 and 430 ppm at 72 h. Exposure to low concentrations of amitraz (30 to 90 ppm) for 72 h reduced feeding about 50% compared to feeding after 24 h (Fig. 1). Beeman and Matsumura (1979) showed that chlordimeform, a formamidine, suppressed feeding in cockroaches and that this antifeedant effect was independent of the repellent effect. The feeding inhibition that we observed with amitraz may be a disruption of feeding behavior via a direct sublethal effect on the central nervous system rather than a repellent effect of amitraz.

No mortality of adults occurred after exposure for 72 h to leaflets treated with up to 4000 ppm amitraz. Toxicity of ingested amitraz could not be determined because insects consumed only small amounts of foliage treated with high concentrations. Similarly, no significant mortality occurred 72 h after immersion of adults in up to 4000 ppm amitraz (Rosemount, $F = 1.38$; df = 5,6; $P = 0.38$: Grand Forks, $F = 0.73$; df = 5, 12; $P = 0.63$).

Larval development, mortality, and behavior. For early-instar larvae that ingested ≤ 1700 ppm amitraz, the relative developmental instar at 10 d (rdi ≥ 3.7) did not differ significantly from the control (rdi = 4.0). Ingestion of 3060 ppm amitraz significantly ($F = 6.88$; df = 5, 12; $P = 0.003$) reduced the relative developmental instar (rdi = 3.1) compared to ingestion of ≤ 525 ppm (rdi ≥ 3.8). Mortality occurred in all treatments at 10 d, although differences were not significant ($F = 2.51$; df = 5, 12; $P = 0.089$). Development time and cumulative mortality to the fourth stadium, pupation, and adult emergence were increased at all treatment levels ($F = 4.20$; df = 3,8; $P = 0.046$ to $F = 86.91$; df = 3,8; $P < 0.0001$) (Fig. 2). Concentrations from 945 ppm to 3060 ppm amitraz had similar

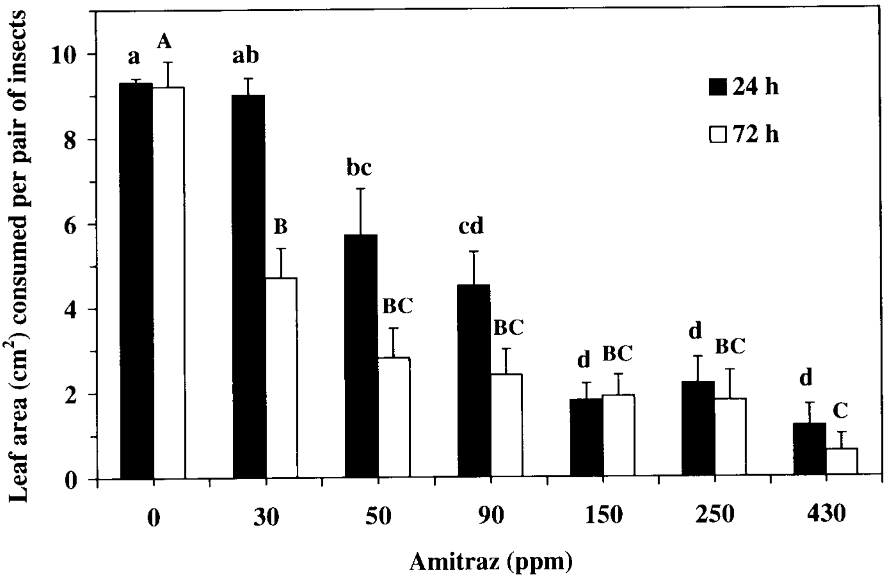

Fig. 1. Mean potato leaf area (cm^2) consumed (± SEM) per 24 h per pair of adult Colorado potato beetles. Leaf disks were replaced with treated disks after 24 and 48 h. Means with the same lowercase letters (24 h) or uppercase letters (72 h) are not significantly different ($P > 0.05$; Scheffe's test).

effects on larval development and mortality. Exposure to 945 ppm amitraz prolonged development to the fourth stadium 2.4 d more than the untreated control and cumulative mortality was 52.3% compared to 0% in the control; adult emergence was delayed 4.7 d and cumulative mortality was 86.7% compared to 6.7% in the control. Leaflets treated with amitraz were repellent to early-instar larvae ($F = 7.95$; df = 5, 12; $P = 0.0002$) only at 3060 ppm. Leaflets treated with ≤ 1700 ppm amitraz were not repellent to early instars.

Greatest mortality of third instars occurred within 24 h after contact exposure to amitraz (Fig. 3A). The only significant difference in mortality between the 24 h and 96 h time periods was at 3060 ppm amitraz ($t = 3.50$; df = 4; $P = 0.036$). Amitraz was not lethal within 96 h at ≤ 525 ppm. Number of third-instar larvae developing to the fourth stadium was significantly less than in the control ($F = 11.42$; df = 5,12; $P = 0.0003$) 72 h after contact with ≥ 525 ppm amitraz (Fig. 3B). Contact with ≤ 1700 ppm amitraz delayed, but did not stop development.

The threshold of reversible tetanization in third instars was between 525 and 945 ppm amitraz by contact application (Fig. 3B). Larvae treated with 945 ppm amitraz were motionless and on their dorsum with extended legs 15 min after exposure and would have fallen from plants in the field. Chlordimeform

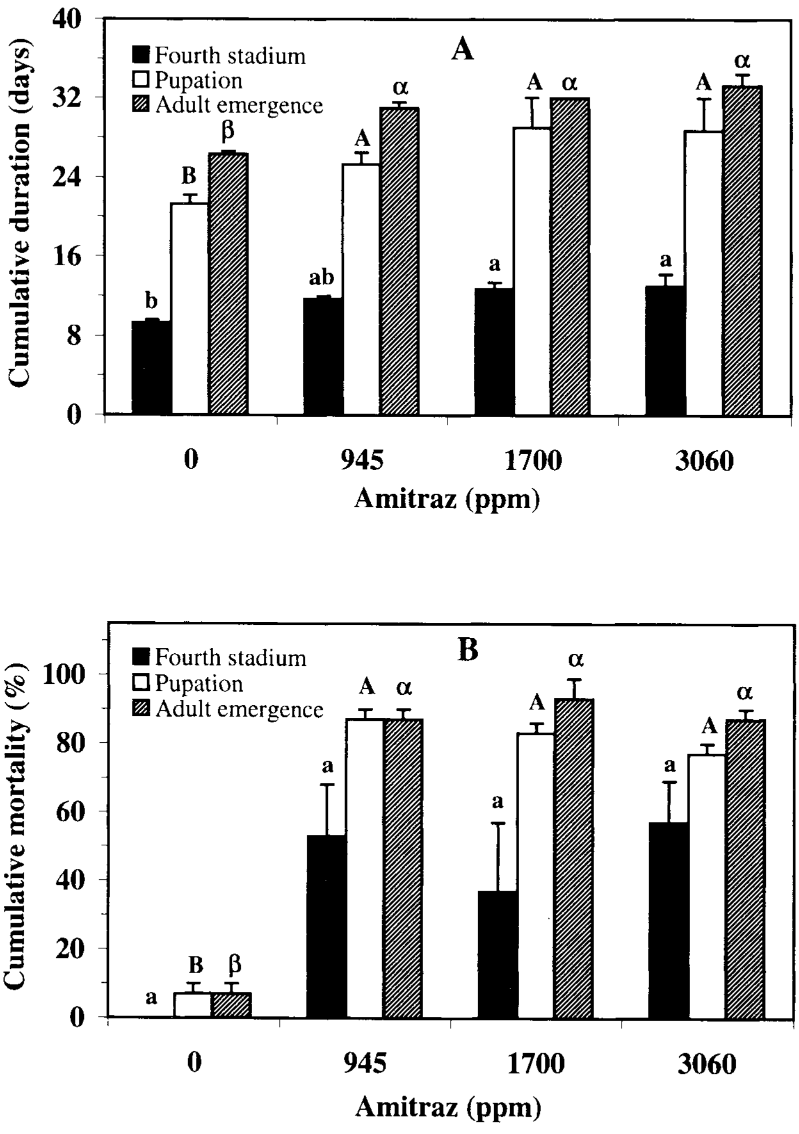

Fig. 2. Effects of amitraz ingestion on mean cumulative duration (A) and on mean cumulative percent mortality (B). First-instars were provided with treated foliage on d 1 and d 7, simulating two field applications. Untreated foliage was provided on d 4-6, and from d 10 until all beetles died or emerged as adults. Vertical bars indicate ± one SEM. Means with the same lowercase letters (fourth stadium), uppercase letter (pupation), or greek letters (adult emergence) are not significantly different ($P > 0.05$; Scheffe's test). Data were transformed to arcsine (percentages) or $\log_{10}$x (days).

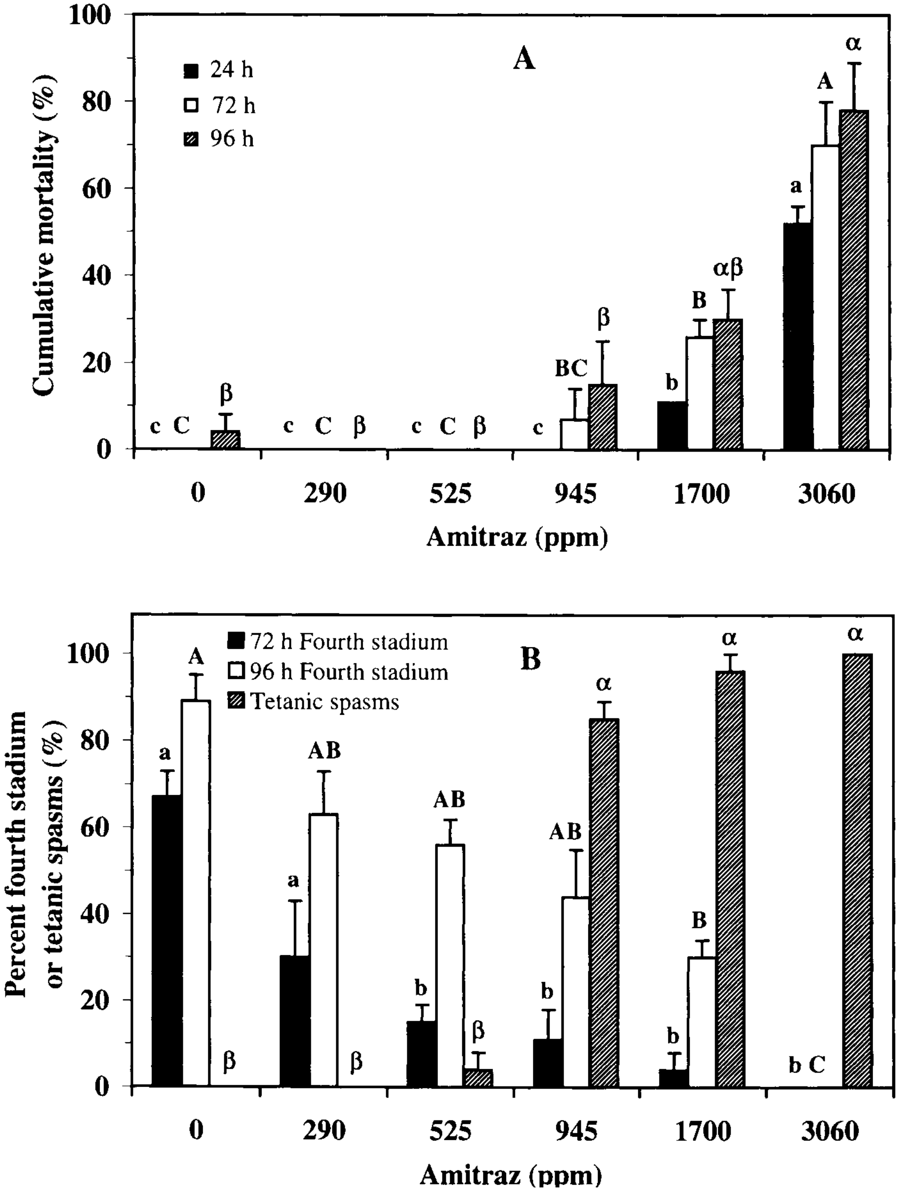

Fig. 3. Effects on third-instars of contact exposure to amitraz on cumulative percent mortality (A) and on mean percent of larvae in the fourth stadium or exhibiting tetanic spasms (B). Vertical bars indicate ± one SEM. Means with the same lowercase letters, uppercase letters, or greek letters are not significantly different ($P > 0.05$; Scheffe's test). Data were transformed to arcsine for analysis.

causes tetanic spasms, continuous wing beating and abnormal patterns of egg-laying in lepidopterans (Lund et al. 1979, Salvisberg et al. 1980, Schreiber and Knowles 1990). Tobacco hornworms, *Manduca sexta* L., consumed chlordimeform-treated tomato leaves, but rapidly developed tremors and then dropped from the leaves (Lund et al. 1979). Hornworm larvae recovered within 1 hr, crawled back onto the plant, and reinitiated feeding. Overall feeding was significantly reduced despite the apparent quick recovery from the sublethal effects.

Determination of larval LC_{50}. Probit analyses yielded significant (P < 0.05) regression coefficients when second and third instars (Virginia population) were exposed to leaflets treated with amitraz or larvae were dipped in amitraz (Table 1). LC_{50}s determined by exposure to treated foliage were 3.2X to 8.1X greater than contact LC_{50} values determined by dipping larvae in treatment solutions. Larvae did not consume much treated foliage, therefore, high concentrations of amitraz were required to cause mortality. The LC_{50} by contact for third instars from the Virginia population (2429 ppm amitraz; Table 1) was similar to the concentration estimated to cause 50% mortality in the Minnesota population (2380 ppm amitraz by interpolation; Fig. 3A), suggesting that the two populations were similarly affected by contact of amitraz.

Table 1. Toxicity of amitraz to second- and third-instar Colorado potato beetle.

Insect stage, (treatment)	*n*	Slope	SEM	LC_{50} (ppm)*	95%FL (ppm)
Second instars (Contact)	576	1.46	0.21	3,502	1,711 - 7,204
Second instars (Ingestion)	384	3.53	0.22	11,263	5,313 - 23,840
Third instars (Contact)	768	2.78	0.18	2,429	2,129 - 2,786
Third instars (Ingestion)	384	2.22	0.21	19,641	14,925 - 31,522

*Mortality determined 72 h after treatment.

Egg mass dip bioassay. Of all egg masses dipped in the highest amitraz concentration of 3320 ppm, 77% hatched; 95% of the egg masses in ≤ 1840 ppm hatched. Although egg hatch was not affected when egg masses were dipped in ≤ 1840 ppm amitraz, formamidines have variable effects on insect eggs. Sparks et al. (1993) found that amitraz was nontoxic to tobacco budworm eggs, but its primary metabolite BTS-27271 was moderately toxic. Streibert and Dittrich (1977) observed that eggs of the Mexican bean beetle, *Epilachna varivestis* (Mulsant), were less susceptible than lepidopteran eggs to toxic effects of chlordimeform.

Field experiments. *Rosemount, MN and Grand Forks, ND.* Amitraz reduced the number of colorado potato beetle larvae, although differences were not always statistically significant (Table 2). Percentage defoliation by Colorado Potato beetle feeding in amitraz-treated plots was significantly lower than the control but not different from esfenvalerate-treated plots. Amitraz had a slightly greater effect on reducing defoliation (Rosemount, 94% reduction; Grand Forks, 85% reduction) than on numbers of Colorado potato beetle larvae (Rosemount, 82% reduction; Grand Forks, 64% reduction). Decreased feeding may be more important than acute mortality of amitraz in reducing damage by Colorado potato beetle, a conclusion supported by our laboratory studies. Yields in amitraz-treated plots were less than in esfenvalerate-treated plots, but greater than in untreated plots (Rosemount, amitraz 67% > control; Grand Forks, amitraz 23% > control). The greater yield difference between amitraz and esfenvalerate treatments at Grand Forks than at Rosemount was probably attributable to the greater numbers of potato leafhoppers at Grand Forks. Amitraz does not control potato leafhopper (Table 2). Aphid numbers in the amitraz-treated plots were low and not significantly different from control plots, but high numbers of aphid were present in the esfenvalerate-treated plots. This is probably due to the relatively low toxicity of amitraz (Tondeur et al. 1993) and the high toxicity of esfenvalerate to aphid predators.

Painter, VA. The number of Colorado potato beetle larvae in the esfenvalerate treatment alone was not significantly different from numbers in untreated plots, indicating substantial resistance to synthetic pyrethroids (Table 3). Although not statistically different, amitraz-treated plots had 56% fewer larvae, 33% less defoliation, and 30% greater yield than plots treated with esfenvalerate alone. Two applications of amitraz were as effective as four applications, and defoliation was comparable when amitraz was applied to small larvae or large larvae (Table 3). Yield was significantly increased in all treatments compared with the control. Esfenvalerate combined with the synergist piperonyl butoxide (PBO) was the best treatment, further indication of resistance to esfenvalerate in the Virginia population.

In summary, amitraz effectively reduced feeding by Colorado potato beetle on potatoes in laboratory and field studies. Low rates (≤ 50 ppm) of amitraz decreased feeding by adults in laboratory tests, therefore, low rate applications of amitraz have potential to reduce feeding damage in the field. Long-term effects of reduced feeding by adults is unknown, but effects could include starvation, desiccation, and reduced longevity and reproductive potential. Other long-term effects of amitraz demonstrated in our study were delayed development and increased mortality. Chlordimeform has been shown to stimulate

Table 2. Field experiments with amitraz applied to potatoes for control of Colorado potato beetle, Minnesota and North Dakota.†

Treatment kg[AI]/ha	No. larvae/plant: Instars I and II	No. larvae/plant: Instars III and IV	Defoliation (%)	Potato leafhopper/ 35 leaves	Aphids/ 35 leaves‡	Total yield (metric t/ha)
ROSEMOUNT, MN						
Amitraz, 0.56	10.5 ± 5.5 b	6.5 ± 4.5 b	1.3 ± 1.1 a	4.5 ± 2.5 a	7.5 ± 4.5 b	27.9 ± 4.2 ab
Esfenvalerate, 0.056	0 ± 0.0 c	0 ± 0.0 c	1.3 ± 0.1 a	0.3 ± 0.3 b	143.7 ± 15.3 a	31.5 ± 1.9 a
Control	37.0 ± 7.5 a	59.7 ± 7.7 a	20.4 ± 9.1 b	5.0 ± 1.0 a	3.7 ± 2.7 b	16.7 ± 0.5 b
	F = 58**	F = 60**	F = 7*	F = 11*	F = 17**	F = 9*
GRAND FORKS, ND						
Amitraz, 0.56	7.3 ± 3.5 ab	19.5 ± 3.2 a	2.0 ± 0.4 b	42.8 ± 7.8 a	–	23.2 ± 1.4 ab
Esfenvalerate, 0.056	0.5 ± 0.5 b	3.0 ± 0.9 b	1.3 ± 0.3 b	2.5 ± 0.5 b	–	30.4 ± 2.1 a
Control	32.0 ± 12.4 a	42.8 ± 4.7 a	13.0 ± 4.9 a	47.5 ± 4.8 a	–	18.9 ± 1.1 b
	F = 13**	F = 14**	F = 10**	F = 91**		F = 10**

† Mean ± SEM.
Means followed by the same letter are not significantly different ($P > 0.05$; Scheffe's test). Asterisks indicate significant differences: * = $P \leq 0.05$; ** = $P \leq 0.01$. Insect counts transformed to $\log_{10}(x+1)$; percentage defoliation transformed to arcsine $\sqrt{}$. ANOVA statistics are shown beneath each respective column; df = 6 (Rosemount) or 8 (Grand Forks).

‡ Green peach aphid.

Table 3. Field experiments with amitraz applied to potatoes for control of Colorado potato beetle, Virginia.*

Treatment, kg[AI]/ha	Mean no. instars III and IV/stem**	% Defoliation on 6 June	Grade A yield (metric t/ha)
Amitraz (4 sprays)‡, 0.56	5.5 bc	29.7 b	6.9 cd
Amitraz (2 sprays)£, 0.56	4.4 c	34.1 b	8.6 bc
Esfenvalerate, 0.04	8.3 a	47.5 b	5.2 cd
Esfenvalerate, 0.04 + PBO§, 0.8	1.5 d	14.6 c	10.2 ab
Control	NS†	91.9 a	0.8 e

* Means within columns followed by the same letter are not significantly different ($P > 0.05$; Ryan's Q test).
** Counts taken on June 6 when greatest numbers of large larvae were present.
† Not sampled on this date because plants in control plots were over 90% defoliated.
‡ First application on 13 May when first and second instars predominated.
£ First application on 28 May when third and fourth instars predominated.
§ Piperonyl butoxide.

hypersensitivity to sex pheromone, interfere with flight and courtship display, stimulate hyperactivity, and effect hyperphagia and anorexia in different species (see refs. in Beeman 1982, Knowles 1982, Haynes 1988). Therefore, chemical control agents like amitraz need not be lethal to be effective. The behavior modification effects of an insecticide can be an important component of its overall efficacy in reducing insect damage. Based on our study and the results of other research (Schreiber and Knowles 1990, Bagwell and Plapp 1992), the ability of amitraz to effectively control pyrethroid-resistant Colorado potato beetle, and its potential to maintain egg and larval parasitoids and predators (Tondeur et al. 1993) deserves further study. If cross resistance to other classes of insecticides does not exist or is slow to develop, rotational use of amitraz with other insecticides might reduce the selection pressure on Colorado potato beetle populations and delay development of resistance to currently-labeled materials.

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