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POTENCY, SPECTRUM AND RESIDUAL ACTIVITY OF FOUR NEW INSECTICIDES UNDER GLASSHOUSE CONDITIONS

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ABSTRACT

The toxicities of four classes of insecticides, emamectin benzoate (avermectin), chlorfenapyr (pyrrole), fipronil (phenylpyrazole), and tebufenozide (benzoylhydrazide) were compared using an artificial diet assay and a residual efficacy assay against several species of Lepidoptera. Emamectin benzoate was consistently the most toxic insecticide; it was 20- to 64,240-times more toxic than the other compounds tested. The LC_{90} values for emamectin benzoate ranged from 0.0050 to 0.0218 ug/ml for six species of Lepidoptera. Similarly, chlorfenapyr displayed consistent toxicity to all species, with LC_{90} values ranging from 1.9 to 4.6 ug/ml. The toxicities of fipronil and tebufenozide varied among the species tested. Fipronil LC_{90} values varied 501-fold (range, 0.64 to 321.3 ug/ml), while tebufenozide toxicity varied 113-fold (range, 0.24 to 27.1 ug/ml) among species tested. In residual efficacy tests conducted in the glasshouse, all compounds were effective (i.e., >90% mortality) at controlling *Heliothis virescens* on garbanzo bean at projected field rates and at 1/10 of projected field rates with fipronil and emamectin benzoate. Emamectin benzoate, chlorfenapyr and tebufenozide were effective at controlling *Spodoptera exigua* on sugar beet at projected field rates. However, mortality with fipronil was reduced to 20% or less at 7 to 14 days after treatment. All compounds at projected field use rates were effective against *Trichoplusia ni* on cabbage, although tebufenozide was the only compound effective at 1/10 of projected field rate for 14 days after treatment. However, tebufenozide was ineffective against *Plutella xylostella* at projected field use rates on cabbage while emamectin benzoate, chlorfenapyr, and fipronil were effective. The potential of these compounds for arthropod pest management are discussed.

Key Words: Chlorfenapyr, emamectin benzoate, fipronil, tebufenozide, residual assay

RESUMEN

La toxicidad de cuatro clases de insecticidas, emamectin benzoate (avermectin), chlorfenapyr (pyrrole), fipronil (phenylpyrazole), y tebufenozide (benzoylhydrazide)fueron comparadas utilizando un ensayo con dieta artificial y un ensayo de eficacia de residuo en contra de varios especies de Lepidoptera. Emamactin benzoate fué consistentemente el insecticida más tóxico, (fué de 20- a 64,240 veces más tóxico que los otros compuestos probados). Los valores de LC_{90} para emamectin benzoate fueron de 0.0050 hasta 0.0218 ug/ml para seis especies de Lepidoptera. Similarmente, chlorfenapyr mostró toxicidad consistente para todos las especies, con valores de LC_{90} desde 1.9 hasta 4.6 ug/ml. Las toxicidades de fipronil y tebufenozide varían entre las especies probadas. Los valores de LC_{90} del Fipronil variaron 501-veces (de 0.64 hasta 321.3 ug/ml), mientras que la toxicidad de tebufenozide varío 113 veces (de 0.24 hasta 27.1 ug/ml), entre las especies probadas. En pruebas de eficacia de residuo llevadas a cabo en invernaderos, todos los compuestos fueron efectivos (i.e. >90% mortalidad) en el control *de Heliothis virescens* en el garbanzo aplicados a la taza proyectada en el campo (o sea a la misma concentración estipulada para el área del campo) y fueron efectivos al 1/10

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de la taza proyectada del campo en el fipronil y el emamectic benzoate. Emamectin benzoate, chlorfenapyr y tebufenozide fueron efectivos en controlar *Spodoptera exigua* en remolacha a la taza proyectada del campo. Sin embargo, la mortalidad con fipronil fué reducida a 20% o menos desde los 7 hasta los 14 dias después del tratamiento. Todos los compuestos aplicados a la taza proyectada del campo fueron efectivos contra *Trichoplusia ni* en repollo, aunque tebufenozide fué el único compuesto efectivo a 1/10 de la taza proyectada del campo durante los 14 dias después del tratamiento.
Sin embargo, tebufenozide no fué efectivo contra *Plutella xylostella* a la taza proyectada del campo en repollo mientras que emamectin benzoate, chlorfenapyr y fiprionil fueron efectivos. Se discuten el potencial de estos compuestos para el manejo de plagas artrópodos.

The insecticide market has been dominated by the organophosphate, carbamate, and pyrethroid classes of insecticides. Recently, a number of new insecticide classes have been discovered and commercialized. Chlorfenapyr, a mitochondrial uncoupler (Black et al. 1994), is effective against both Acarina and Lepidoptera (Lovell et al. 1990, Wier et al. 1994, Ahn et al. 1996) in laboratory and field tests. Fipronil, an antagonist of the GABA-gated chloride channel (Bloomquist 1994), has efficacy against a number of insect pests (Colliot et al. 1992, Burris et al. 1994, Hoy & Dunlap 1995). Emamectin benzoate is a second generation avermectin with superior activity against lepidopterans compared with abamectin (Dybas et al. 1989, Jansson & Dybas 1997). Tebufenozide, an ecdysone-receptor agonist (Retnakaran et al. 1995), has demonstrated activity against many lepidopterans (Chandler 1994, Smagghe & Degheele 1994, Ishaaya et al. 1995).

The purpose of this research was to compare the potencies, spectrum, and residual effectiveness of these compounds against a broad panel of lepidopteran pests. These comparisons will help to provide information on the potential strengths and weaknesses of each compound in crop protection.

Material And Methods

Chemicals

Emamectin benzoate (Proclaim® 0.16 EC) was obtained from Merck & Co., Inc. (Rahway, NJ). Tebufenozide (Confirm 2F) was obtained from Rohm & Haas (Spring House, PA). Chlorfenapyr (Rampage® 10% EC) and fipronil (Ascend® 5% SC) were obtained commercially. These formulations were marketed for use in cotton and were presumed to be optimized.

Insect Strains. Tobacco budworm, *Heliothis virescens* (F.), and soybean looper, *Pseudoplusia includens* (Walker) were obtained from the USDA, ARS, Southern Insect Management Laboratory, Jamie Whitten Research Center, Stoneville, MS. Diamondback moth, *Plutella xylostella* (L.), beet armyworm, *Spodoptera exigua* (Hubner) and cabbage looper, *Trichoplusia ni* (Hubner) were obtained from Ecogen Co. (Langhorne, PA). Fall armyworm, *Spodoptera frugiperda* (J. E. Smith) were obtained from the USDA ARS, Insect Biology and Population Management Research Laboratories, Tifton, GA. *Plutella xylostella* eggs were shipped on artificial diet to Ricerca, Inc. (Painesville, OH) and held at 24 ± 2°C and 50 ± 20% RH until needed. *Heliothis virescens* and *S. exigua* eggs were surface sterilized upon arrival at Ricerca, Inc. with sodium hypochlorite solution (0.2%), dried, and then held at 11.0 ± 0.2°C until needed. All other eggs were shipped to Ricerca, Inc. and held at 11.0 ± 0.2°C until needed. Eggs were placed in disposable plastic cups with clipped foliage at 28 ± 2°C and 50 ± 20% RH two d before use. Larvae were tested as neonates (12 - 24 h) except *P. xylostella,* which were 6 d old due to the small size and delicacy of neonate *P. xylostella*.

Diet Assay

Methods were similar to those described previously (Jansson et al. 1998). Serial dilutions were made from formulated products in combination with a surfactant (0.01% Triton X-155) and deionized H_20. Controls consisted of 0.01% Triton X-155 in deionized H_20. *Plutella xylostella* diet was obtained from Southland Products (Lake Village, AR). Artificial diet for all Lepidopterans, except *P. xylostella*, was prepared using established methods (King and Hartley 1985). Agar was heated in an autoclave (121°C) until dissolved and then added to a blender (3.8 liter) containing the dry ingredients. The agar and dry ingredients were blended for 1 min and transferred to a steam-jacketed kettle maintained at 70°C. The diet was dispensed (500 µl per well) into diet trays (C-D International, Inc., Pitman, NJ) using a semi-automated diet filler (Model MDF-100, C-D International, Inc., Pitman, NJ). Diet trays were cooled, wrapped in plastic, and used within 48 h after preparation.

An 50 µl aliquot of each dose of each test concentration was pipetted onto the surface of the diet in each of 16 individual wells per dose. Trays were shaken slightly to ensure that the aliquot evenly covered the surface of the diet. After treated diet was air dried, neonates were transferred onto the diet (one per well) and the wells

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sealed using plastic adhesive strips. The tops of the plastic strips were pierced for ventilation. The criterion for death was the ability of the larvae to right itself. Mortality was recorded 6 d after application (Jansson et al. 1998).

Residual Efficacy Assays

Methods were similar to those described previously (Jansson et al. 1996, 1997). A custom built track sprayer system was used to apply insecticides. Treatments were applied using a calibrated double-nozzle (TJ8001E, Sprayer Systems, Wheaton, IL) track sprayer that delivered 100 ml of spray solution to 7-10 plants over 2 meters at 3.5 kg/cm^2. Plants 14-20 days old were sprayed with chlorfenapyr, emamectin benzoate, fipronil, and tebufenozide at estimated field use rates (224.2, 8.42, 56.0 and 140.0 g ai/ha, respectively) and 10% of these rates. Insecticides were applied in combination with the nonionic surfactant Leaf-Act 80 (PureGro, W. Sacramento, CA) at a rate of 0.58 l/ha (0.0625%). Controls consisted of the surfactant treatment alone. Plants were held in a glasshouse at 24 ± 6°C after treatment. Five replicate leaf cuttings from different plants were infested with larvae on 0, 4, 7, 10 and 14 days after treatment (DAT). Foliage was clipped and placed in Petri plates containing 20 ml of 1.8% water agar. Clippings were infested with 10-12 larvae and mortality was assessed after 4 d. Garbanzo bean, *Cicer arietinum* (L.) cv. Burpee Garbanzo 5024, and sugar beet, *Beta vulgaris* L. cv. USH-11, were used to test residual effectiveness at controlling *H. virescens* and *S. exigua*, respectively. Cabbage, *Brassica oleracea* var. *capitata* L. cv. Jersey Wakefield, was used to assess residual effectiveness against *T. ni* and *P. xylostella*. A compound was considered effective if mortality remained above 90%.

Data Analysis

Data from the diet assays were analyzed using probit analysis models in the POLO-PC program (Russell et al. 1977). Significant difference between LC values was based on overlap of 95% fiducial limits. The percentage mortality data of the residual efficacy assays was arcsine transformed and analyzed by ANOVA. Means within each rate range were separated by the Waller-Duncan K-ratio *t*-test (SAS Institute, 1993).

Results

Diet Assay

Emamectin benzoate was the most toxic compound tested. The Lepidopteran species tested were 20- to 64,260-times more sensitive to emamectin benzoate than to the other three compounds (i.e., *T. ni* was 20-times more sensitive to emamectin benzoate than tebufenozide, and *S. exigua* was 64,240-times more sensitive to emamectin benzoate than fipronil} (Table 1). Fiducial limits for LC_{90} values against most Lepidoptera overlapped, indicating that emamectin benzoate was equally potent against most Lepidoptera tested. *Spodoptera exigua* and *P. xylostella* were the most sensitive species to emamectin benzoate (LC_{90} = 0.005 and 0.0053 ug/ml, respectively), while *T. ni* and *P. includens* were the least sensitive (LC_{90} = 0.0125 - 0.0218 ug/ml, respectively). There was a 4-fold difference in LC_{90} values between the least sensitive and most sensitive species.

Chlorfenapyr toxicity was consistent among species. The LC_{90} values had a narrow range (1.9-4.6 ug/ml) with fiducial limits ranging from 1.6-6.5 ug/ml (Table 1). The slopes of the chlorfenapyr concentration responses against Lepidoptera were the steepest (3.9-8.2) among the four compounds tested.

In contrast to chlorfenapyr and emamectin benzoate, there was wide variation in sensitivity to fipronil among the six species tested. *Plutella xylostella* was over 10 to 502-times more sensitive to fipronil than the other five species tested (Table 1). LC_{90} values for *H. virescens, P. includens, T. ni* and *S. frugiperda* ranged between 6.4 and 18.8 ug/ml and had overlapping fiducial limits. *Spodoptera exigua* was the least sensitive species to fipronil (LC_{90} = 321.3 ug/ml).

There also was wide variation in sensitivity of Lepidoptera to tebufenozide with *Trichoplusia ni* being the most sensitive species (LC_{90} = 0.24 ug/ml, Table 1). *Pseudoplusia includens* and *S. frugiperda* (LC_{90} = 2.6 and 2.1ug/ml, respectively) were almost equally sensitive to tebufenozide. *Spodoptera exigua* and *P. xylostella* were approximately 33-times and 51-times more tolerant, respectively, of tebufenozide than *T. ni*. The Lepidopteran most tolerant of tebufenozide in these tests was *H. virescens,* which was 113-times more tolerant of tebufenozide than *T. ni*.

Residual Efficacy Assays

All compounds at projected field rates were effective at controlling *H. virescens* up to 14 DAT except tebufenozide, which was effective up to 10 DAT (Table 2). Emamectin benzoate also caused 100% mortality on all evaluation dates when applied at low rate (0.84 g AI/ha). Fipronil was effective at controlling *H. virescens* at all evaluation dates up to 14 DAT at low rate (5.6 g AI/ha). Mortality in these treatments was comparable to that produced by emamectin benzoate. The low rate of chlorfenapyr (22.4 g AI/ha) had lower percentage mortality on 7 DAT than the corresponding rates of emamectin benzoate and fipronil, but mortality increased to 100.0% on 14 DAT. This may have

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TABLE 1. CONCENTRATION-MORTALITY RESPONSES VARIOUS LEPIDOPTERAN PESTS TO CHLORFENAPYR, FIPRONIL, EMAMECTIN BENZOATE AND TEBUFENOZIDE AND DIET ASSAYS.

Insecticide	*Heliothis virescens*	*Spodoptera exigua*	*Plutella xylostella*	*Trichoplusia ni*	*Pseudoplusia includens*	*Spodoptera frugiperda*
Chlorfenapyr LC_{50} (ug/ml)	1.5	2.2	1.5	1.4	2.2	1.2
	(1.3 - 1.7)	(1.8 - 2.6)	(1.3 - 1.8)	(1.1 - 1.6)	(1.8 - 2.4)	(1.0 - 1.5)
LC_{90}- (ug/ml)	2.3	4.6	2.7	2.2	3.1	1.9
	(1.9 - 2.9)	(3.7 - 6.5)	(2.2 - 3.7)	(1.9 - 3.3)	(2.7 - 3.8)	(1.6 - 2.9)
Slope	7.2 + 1.2	3.9 + 3.6	5.3 + 1.0	6.8 + 2.0	8.2 + 1.6	6.5 + 0.7
	(n = 353)	(n = 349)	(n = 219)	(n = 275)	(n = 382)	(n = 478)
Emamectin LC_{50} (ug/ml)	0.0034	0.*026	0.0014	0.0072	0.0058	0.0029
Benzoate	(0.0023-0.0049)	(0.3021 - 0.0033)	(0.0004 - 0.0029)	(0.0051 - 0.00091)	(0.0020 - 0.3130)	(0.0023 - 3.3035)
LC_{90} (ug/ml)	0.0086	0.3050	0.0053	0.0125	0.0218	0.0066
	(0.0058 - 0.0185)	(0.0039 - 0.0087)	(0.0026 - 0.0718)	(0.0098 - 0.0215)	(0.0105 - 0.1158)	(0.0052 - 0.0099)
Slope	3.1 + 0.4	4.7 + 3.9	2.2 + 0.3	5.4 + 3.9	2.2 + 3.3	3.6 + 3.6
	(n = 324)	(n = 329)	(n = 232)	(n = 252)	(n = 356)	(n = 238)
Fipronil LC_{50} (ug/ml)	5.8	95.2	3.17	5.9	2.4	2.4
	(3.2 - 8.7)	(66.7 - 139.8)	(3.37 - 0.32)	(4.2 - 7.6)	(1.8 - 3.1)	(1.0 - 5.0)
LC90 (ug/ml)	18.8	321.3	3.64	12.4	6.4	8.8
	(12.0 - 52.3)	(203.9 - 718.3)	(0.34 - 2.57)	(9.3 - 23.7)	(4.7 - 13.6)	(14.3 - 69.5)
Slope	2.5 + 0.3	2.4 + 0.1	2.2 + 0.3	4.0 + 0.8	3.0 + 0,5	2.2 + 0.3
	(n = 444)	(n = 1280)	(n = 208)	(n = 126)	(n = 281)	(n = 252)
Tebufenozide LC_{50} (ug/ml)	8.2	2.2	6.2	0.1	1.0	0.95
	(6.2 - 10.6)	(1.5 - 2.9)	(3.7 - 8.2)	(0.07 - 0.13)	(0.9 - 1.2)	(0.74 - 1.1)
LC_{90} (ug/ml)	27.1	7.8	12.3	0.24	2.6	2.1
	(19.6 - 44.3)	(5.6 - 13.1)	(9.2 - 24.6)	(0.19 - 0.34)	(2.2 - 3.3)	(1.8 - 2.8)
Slope	2.5 + 0.3	2.3 + 3.4	4.3 + 0.5	3.4 + 0.4	3.1 + 0.3	3.6 = 0.6
	(n = 318)	(n = 319)	(n = 748)	(n = 716)	(n = 540)	(n = 459)

TABLE 2. RESIDUAL ASSAY ON GARBANZO BEANS USING H. VIRESCENS. TREATMENTS WERE AT FIELD RATE AND 1/10 FIELD RATE OF INSECTICIDE WITH LEAFACT 80 (0.58 L/HA) AS AN ADJUVANT. FIVE REPLICATES WERE USED FOR EACH TREATMENT.

	Rate	4 DAT		7 DAT		10 DAT		14 DAT	
Insecticide	g ai/ha	% Mort.	(SEM)	% Mort.	(SEM)	% Mort.	(SEM)	% Mort.	(SEM)
Projected Field Rate									
Chlorfenapyr	224.2	103.0 a	0.0	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0
Emamectin Benzoate	8.4	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0
Fipronil	56.0	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0
Tebufenozide	140.0	100.0 a	0.0	98.0 a	2.0	97.1 a	2.9	92.9 b	7.1
Control	LeafAct 80	11.4 b	5.0	31.0 b	10.8	36.9 b	17.2	30.1 c	16.1
1/10 Projected Field Rate									
Chlorfenapyr	22.4	85.5 a	9.2	76.5 b	9.6	85.3 ab	9.0	100.0 a	0.0
Emamectin Benzoate	0.84	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0
Fipronil	5.6	100.0 a	0.0	100.0 a	0.0	94.3 a	5.7	100.0 a	0.0
Tebufenozide	14.0	89.2 a	6.6	90.0 ab	10.0	58.7 b	8.4	81.0 a	11.2
Control	LeafAct 80	11.4 b	5.0	31.0 c	10.8	36.9 c	17.2	30.1 c	16.1

[a]Waller-Duncan Ranking, va lues within rates and DAT having the same letter are not significantly different ($P < 0.05$).

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been due, in part, to the nutritional quality of the older leaves used on these DAT, as control mortality ranged from 30.1 to 36.9% on evaluations from 7 to 14 DAT. At the low rate (14.0 g ai/ha) tebufenozide caused mortality ranging from 68.7 to 90.0%, although mortality only differed from other insecticide treatments on 10 DAT. It should be noted that a number of dead and live tebufenozide-treated *H. virescens* larvae showed molting deformities characteristic of tebufenozide toxicity (Retnakaran et al. 1995).

The results of the residual efficacy tests on sugar beet using *S. exigua* were different from those on garbanzo bean**.** Chlorfenapyr, emamectin benzoate and tebufenozide resulted in complete or nearly complete control of *S. exigua* on sugar beet for up to 14 DAT when applied at the high rates (Table 3). Emamectin benzoate also caused 100% mortality for up to 14 DAT when applied at the low rate. Chlorfenapyr was not significantly different from emamectin benzoate up to 14 DAT. However, at 14 DAT chlorfenapyr treatments caused only 66.8% *S. exigua* mortality. Tebufenozide was effective for up to 4 DAT when applied at the low rates (14.0 g AI/ha). Phytotoxicity (i.e., chlorosis) was noted in sugar beets treated with chlorfenapyr at the projected field rate. As in the case of *H. virescens,* a number of dead and alive tebufenozide-treated *S. exigua* larvae showed molting deformities characteristic of tebufenozide toxicity. Fipronil at the projected field rate (56 g AI/ha) was effective at controlling *S. exigua* for up to 4 DAT. Mortality dropped markedly by 7 DAT and was similar to controls at 10 and 14 DAT (Table 3). Mortality caused by fipronil at the low rate was comparable to control mortality.

The high rates of chlorfenapyr, emamectin benzoate and fipronil resulted in 100% mortality of *P. xylostella* on cabbage for the duration of the test (Table 4). Emamectin benzoate and fipronil at the low rates (0.84 and 5.6 g AI/ha, respectively) caused 100% mortality up to 4 DAT. Emamectin benzoate also caused 95% mortality at 7 DAT. At the low rate, chlorfenapyr was ineffective from 4 to 14 DAT.

Tebufenozide was the only compound that was ineffective against *P. xylostella* when applied at the high rate (Table 4). The highest level of mortality caused by tebufenozide during the course of the test was 82.5% on 7 DAT. Mortality at the low rate of tebufenozide was comparable to controls between 4 and 14 DAT.

All compounds were effective against *T. ni* in the residual efficacy tests up to 10 DAT when applied to cabbage at their high rates. At 14 DAT, fipronil and tebufenozide caused less than 90% mortality, although these treatments were not significantly different from chlorfenapyr or emamectin benzoate. Emamectin benzoate was the only insecticide that caused 100% mortality of *T. ni* for the duration of the test (Table 5). However, differences among compounds were more apparent at their low rates. The low rate of tebufenozide (14.0 g AI/ha) caused 82.0-96.4% mortality of *T. ni* between 0-14 DAT. At 14 DAT, tebufenozide ranked higher than any of the other compounds tested (Table 5). At the low rate (0.84 g AI/ha), the efficacy of emamectin benzoate for control of *T. ni* started to diminish at 4 DAT. Control with emamectin benzoate at the low rate ranked lower than that from tebufenozide at its low rate (14.0 g AI/ha) on 10 and 14 DAT, and ranked lower than that from chlorfenapyr at its corresponding rate (22.4 g AI/ha) at 10 DAT. At the low rate, chlorfenapyr was ranked lower than tebufenozide at 14 DAT. Fipronil at low rate (5.6 g AI/ha) was only effective on 0 DAT, and at 4 DAT all the other insecticides outperformed fipronil. At 14 DAT only tebufenozide was different from control at the low rate.

Discussion

Emamectin benzoate was consistently the most potent compound tested. It was at least 1-5 orders of magnitude more potent than all other compounds evaluated. Emamectin benzoate was potent against a wide spectrum of Lepidoptera species; toxicity differed by only 4-fold among the Lepidoptera tested.

Chlorfenapyr was the second most potent compound against most Lepidoptera, followed by tebufenozide and fipronil. Like emamectin benzoate, chlorfenapyr demonstrated broad spectrum activity, and was equally effective against all Lepidoptera tested. The spectrum of tebufenozide and fipronil were more variable. Of these three compounds, chlorfenapyr was the most potent to *H. virescens*, *S. exigua* and *S. frugiperda*, while tebufenozide was the most potent to *T. ni* and fipronil the most potent to *P. xylostella*.

Residual efficacy data under glasshouse conditions correlated with the spectrum and potency data. Emamectin benzoate and fipronil were particularly effective at controlling *H. virescens* when applied at high rates and at 10% of these rates. Tebufenozide and chlorfenapyr were effective at the field rate against *H. virescens* for 10 and 14 DAT, respectively. Emamectin benzoate and chlorfenapyr were more effective at controlling *S. exigua* than tebufenozide and, particularly, fipronil, which agreed with the diet bioassay data. It should be noted that a number of larvae treated with tebufenozide had molting deformities characteristic of tebufenozide toxicity. Some of these deformed larvae would have probably succumbed within a few days after the 4-day mortality assessment used in the residual efficacy test (Jansson et al. 1998). Tebufenozide was the least effective compound at controlling *P. xylostella,* which also concurred with the diet bioassay data.

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TABLE 3. RESIDUAL ASSAY ON SUGAR BEETS USING *S. EXIGUA* TREATMENTS WERE AT FIELD RATE AND 1/13 FIELD RATE OF INSECTICIDE WITH LEAFACT 80 (0.58 L/HA) AS AN ADJUVANT. FIVE REPLICATES WERE USED FOR EACH TREATMENT.

	Rate	0 DAT		4 DAT		7 DAT		10 DAT		14 DAT	
Insecticide	g ai/ha	% Mort.	(SEM)	% Mort.	(SEM)	% Mort.	(SEM)	% Mort.	(SEM)	% Mort.	(SEM)
Projected Field Rate											
Chlorfenapyr	224.2	82.0 a[a]	18.0	100.C a	0.0	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0
Emamectin Benzoate	8.4	100.0 a	0.0	100.C a	0.0	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0
Fipronil	56.0	83.3 a	8.8	98.0 a	2.0	5.3 b	2.2	20.7 b	9.5	10.5 b	5.1
Tebufenozide	140.0	100.0 a	0.0	100.C a	0.0	96.0 a	2.6	100.0 a	0.0	100.0 a	0.0
Control	LeafAct 80	10.5 b	6.1	10.0 b	10.0	0.0 c	0.0	7.3 b	2.3	4 0 b	4.0
1/10 Projected Field Rate											
Chlorfenapyr	22.4	100.0 a	0.0	100.0 a	0.0	80.0 ab	20.0	96.4 a	3.6	66.8 ab	13.7
Emamectin Benzoate	0.84	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0
Fipronil	5.6	19.3 b	13.2	1.7 b	1.7	2.0 c	2.0	4.3 c	2.4	0.0 c	0.0
Tebufenozide	14.0	100.0 a	0.0	96.7 a	3.3	45.9 b	16.2	53.8 b	20.2	58.9 b	19.0
Control	LeafAct 80	10.5 b	6.1	10.0 b	10.0	0.0 c	0.0	7.3 c	2.3	4.0 c	4.0

[a]Waller-Duncan Ranking, values within rates and DAT having the same letter are not significantly different ($P < 0.05$).

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TABLE 4. RESIDUAL ASSAY ON CABBAGE USING *P. XYLOSTELLA*. TREATMENTS WERE AT FIELD RATE AND 1/10 FIELD RATE OF INSECTICIDE WITH LEAFACT 80 (0.58 L/HA) AS AN ADJUVANT. FIVE REPLICATES WERE USED FOR EACH TREATMENT.

	Rate	0 DAT		4 DAT		7 DAT		10 DAT		14 DAT	
Insecticide	g ai/ha	% Mort.	(SEM)	% Mort.	(SEM)	% Mort.	(SEM)	% Mort.	(SEM)	% Mort.	(SEM)
Projected Field Rate											
Chlorfenapyr	224.2	100.0 a[a]	0.0	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0
Emamectin Benzoate	8.4	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0
Fipronil	56.0	98.5 ab	1.5	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0
Tebufenozide	140.0	81.8 b	10.6	74.4 b	9.3	82.5 a	11.9	44.8 b	13.7	50.0 b	21.3
Control	LeafAct 80	14.3 c	5.0	4.4 c	4.4	2.5 c	2.5	6.3 c	4.4	12.0 c	9.7
1/10 Protected Field Rate											
Chlorfenapyr	22.4	89.5 a	5.1	50.7 b	18.7	46.9 b	14.0	49.8 ab	20.7	55.8 ab	21.7
Emamectin Benzoate	0.84	100.0 a	0.0	100.0 a	0.0	95 0 a	5.0	78.0 ab	15.6	72.0 a	
Fipronil	5.6	100.0 a	0.0	100.0 a	0.0	82.5 a	10.9	66.5 ab	17.4	56.0 ab	14.7
Tebufenozide	14.0	52.9 b	14.2	6.2 c	4.1	15.7 c	8.2	15.4 b	5.4	9.5 b	6.6
Control	LeafAct 80	14.3 c	5.0	4.4 c	4.4	2.5 c	2.5	6.3 b	4.4	12.0 b	9.7

[a]Waller-Duncan Ranking, values w-thin rates and DAT having the same letter are not significantly different ($P < 0.05$).

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TABLE 5. RESIDUAL ASSAY ON CABBAGE USING *T. NI*. TREATMENTS WERE AT FIELD RATE AND 1/10 FIELD RATE OF INSECTICIDE WITH LEAFACT 80 (0.58 L/HA) AS AN ADJUVANT. FIVE REPLICATES WERE USED FOR EACH TREATMENT.

	Rate	0 DAT		4 DAT		10DAT		14 DAT	
Insecticide	g ai/ha	% Mort.	(SEM)	% Mort.	(SEM)	% Mort.	(SEM)	% Mort.	(SEM)
Projected Field Rate									
Chlorfenapyr	224.2	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0	94.7 a	5.3
Emamectin Benzoate	8.4	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0	100.0 a	0.0
Fipronil	56.0	100.0 a	0.0	96.0 a	4.0	98.5 a	1.5	85.6 a	9.9
Tebufenozide	140.0	100.0 a	0.0	100.0 a	0.0	97.5 a	2.5	80.0 a	
Control	LeafAct 80	8.2 b	6.5	4.3 b	2.7	6.0 b	4.0	0.0 b	0.0
l/10 Projected Field Rate									
Chlorfenapyr	22.4	98.0 a	2.0	80.0 a	12.2	74.3 a	13.1	13.3 b	13
Emamectin Benzoate	0.84	100.0 a	0.0	83.6 a	8.4	21.3 b	13.6	2.5 b	2.5
Fipronil	5.6	98.0 a	2.0	36.5 b	10.2	5.8 b	2.4	2.2 b	2.2
Tebufenozide	14.0	96.4 a	3.6	86.0 a	9.3	98.5 a	1.5	82.0 a	13.2
Control	LeafAct 80	8.2 b	6.5	4.3 c	2.7	6.0 b	4.0	0.0 b	0.0

[a]Waller-Duncan Ranking, values within rates and DAT having the same letter are not significantly different ($p < 0.05$).

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Emamectin benzoate was the only compound that resulted in complete control (i.e., 100% mortality) of *T. ni* through 14 DAT when applied at the high rates, although control achieved with the other insecticides at equivalent rates was also acceptable (Table 5). Tebufenozide was superior to all other compounds at controlling *T. ni* when applied at the low rates.

A number of factors, such as photostability, translaminar uptake, and leaf nutritional status, will effect residual efficacy (Verkerk & Wright 1996). In our studies the concentration-response appeared to correlate with residual efficacy in the two cabbage pests. At field rate, emamectin benzoate was equally effective at controlling *T. ni* and *P. xylostella*, causing 96.7-100.0% mortality to both insects for the duration of the test. Emamectin benzoate was only effective up to 4 DAT against *T. ni* at the low rate (Table 5), while against *P. xylostella* it was effective for up to 7 DAT (Table 4). In diet assays, *T. ni* was approximately 2-times more tolerant of emamectin benzoate compared with *P. xylostella* (Table 1). This may be the reason for the different response in the residual efficacy assays at the low rate between the two species.

Fipronil was effective against both species at the field rate. At the low rate, fipronil was effective for up to 7 DAT against *P. xylostella* (Table 4), but it was ineffective against *T. ni* after 0 DAT (Table 5). Again, these data confirm diet assay results. *Plutella xylostella* was the most sensitive species to fipronil based on LC values, while *T. ni* was less sensitive to fipronil (Table 1).

Chlorfenapyr was effective against both species for the duration of the test when applied at field rate (Tables 4 and 5). These data agree with results from the diet assay, which showed no difference in LC_{90} values between these two species.

Tebufenozide was efficacious against *T. ni* and remained effective at controlling this insect at both rates for the duration of the test (Table 5). However, tebufenozide was ineffective at both rates against *P. xylostella*, even on 0 DAT. These data confirm diet assay results. *T. ni* was the most sensitive species to tebufenozide based on LC_{90} values, whereas *P. xylostella* was 51-times more tolerant of tebufenozide compared with *T. ni* (Table 1).

Collectively, these data show that all four compounds have potential for controlling Lepidoptera pests. Emamectin benzoate and chlorfenapyr controlled a broader spectrum of lepidopteran pests and for this reason should have a broader utility in crop protection. Tebufenozide and fipronil controlled a narrower range of lepidopteran pests, but have already demonstrated utility under field conditions against certain lepidopteran pests.

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