DEVELOPMENT OF A NOVEL SOLUBLE GRANULE FORMULATION OF EMAMECTIN BENZOATE FOR CONTROL OF LEPIDOPTEROUS PESTS

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ABSTRACT

Six solid formulations of emamectin benzoate (one wettable powder (WP) blend, one wettable dispersible granule (WG), and four soluble granules (SG)) were compared with an emulsifiable concentrate (EC) formulation for their residual effectiveness at controlling tobacco budworm, *Heliothis virescens* (F.), beet armyworm, *Spodoptera exigua* (Hübner), and cabbage looper, *Trichoplusia ni* (Hübner), in three glasshouse tests. Emamectin benzoate was applied to plants at two rates in each trial (8.4 and 0.084 g ai/ha). Results from the glasshouse studies showed that most formulations were comparable at controlling all lepidopterous pests tested. Four field trials conducted in Florida confirmed that all formulations were comparable in their effectiveness at controlling populations of lepidopterous pests on vegetables, including diamondback moth, *Plutella xylostella* (L.), on cabbage, southern armyworm, *Spodoptera eridania* (Cramer), on pepper, and *T. ni* and *S. exigua* on celery. These studies identified a novel SG formulation of emamectin benzoate that was comparable to the EC formulation in its effectiveness at controlling lepidopterous pests, but superior to the EC in terms of safety to man and the environment. This novel SG formulation is currently being developed for control of lepidopterous pests on a variety of crops.

Key Words: Avermectin, emamectin benzoate, formulation, residual efficacy

RESUMEN

El efecto residual de seis formulaciones sólidas de benzoato de emamectina (una mezcla de polvo humedecible, gránulos humedecibles dispersables, y cuatro gránulos solubles) fue comparado con el de un concentrado emulsificable en el control de *Heliothis virescens* (F.), *Spodoptera exigua* (Hübner) y *Trichoplusia ni* (Hübner) en tres pruebas, en tres invernaderos. El benzoato de emamectina fue aplicado a las plantas a dos concentraciones en cada prueba (8.4 y 0.084 g ia/ha). Los resultados de los estudios de invernadero mostraron que la mayoría de las formulaciones fueron comparables con en el control de todos los lepidópteros probados. Cuatro pruebas de campo conducidas en la Florida confirmaron que todas las formulaciones fueron comparables en su efectividad al controlar poblaciones de lepidópteros plagas de vegetales, incluyendo *Plutella xylostella* (L.), en col, *Spodoptera eridania* (Cramer) en pimiento, y *T. ni* y *S. exigua* en apio. Los estudios identificaron una nueva fórmula de gránulos solu-

bles de benzoato de emamectina que fue comparable con el concentrado emulsionable en cuanto a su efectividad al controlar lepidópteros plagas pero es superior al concentrado emusionable en términos de seguridad al hombre y el ambiente. Esta nueva formulación de gránulos soluble es actualmente desarrollada para el control de lepidópteros plagas de varios cultivos.

Avermectins, a family of 16-membered macrocyclic lactones produced by the soil microorganism, *Streptomyces avermitilis* MA-4680 (NRRL 8165), are an important tool in animal health, human health and crop protection (Jansson & Dybas 1997). The major component of the fermentation, avermectin B_1 (= abamectin), is a mixture of B_{1a} (≥ 80%) and B_{1b} (≤ 20%) (Dybas et al. 1989). The discovery, spectrum of activity, safety, and applications of avermectins for control of arthropods have been reviewed extensively (Campbell et al. 1984, Dybas 1989, Lasota & Dybas 1991, Jansson & Dybas 1997).

Emamectin benzoate (MK-0244; PROCLAIM™) is a semisynthetic derivative of abamectin and is currently being developed for control of lepidopterous pests on a variety of vegetable crops worldwide (Dybas et al. 1989, Jansson & Dybas 1997, Jansson et al. 1997). Impressive, broad spectrum control of lepidopterous pests on a variety of vegetable crops in the field has been demonstrated at low use rates (8.4-16.8 g ai/ha) (Jansson & Lecrone 1992, Leibee et al. 1995, Jansson et al. 1996, 1997, Jansson & Dybas 1997).

Earlier attempts to develop solid formulations of avermectin insecticides failed due to their low water solubility and selection of unsuitable delivery systems. This was especially difficult with abamectin, which is about 3-fold less soluble in water than emamectin benzoate (Merck, unpublished data). Recently, Jansson et al. (1996) found that wettable powder (WP) formulations of emamectin benzoate had potential for controlling lepidopterous pests on vegetables under glasshouse and field conditions. It is well known that changes in the constituents of formulations may have marked effects on the behavior of arthropods and concomitant product efficacy (Hartley & Graham-Bryce 1980, Edwards et al. 1994). Additionally, changes in formulation composition can significantly affect the overall safety of pesticide products to man and the environment (Hudson & Tarwater 1988). The present studies extended our earlier work (Jansson et al. 1996) to develop a novel solid formulation of emamectin benzoate that was as effective as a liquid emulsifiable concentrate (EC) formulation at controlling lepidopterous pests. The soluble granule (SG) formulations reported herein are novel to the agrichemical industry and represent a significant breakthrough in avermectin delivery systems for agriculture.

Materials and Methods

Formulations Tested

Experimental formulations tested were of three types: dry powder blends, wettable dispersible granules, and soluble granules (Table 1); each of these was compared with the effectiveness of a 0.16 EC formulation at controlling lepidopterous pests. The dry powder blend (formulation 81) was prepared by combining all ingredients (ai, diluent, surfactant) and then blending until homogeneous. The wettable dispersible granule (WG) (83) and soluble granule (SG) formulations (85, 86, 87, 88) were prepared by combining all ingredients (ai, diluents, surfactants), blending until homogeneous, and then granulating. The EC formulation (formulation 49) was prepared by

TABLE 1. FORMULATION TYPE, COMPOSITION, AND PERCENTAGE OF AVAILABLE AI OF SEVEN FORMULATIONS OF EMAMECTIN BENZOATE (MK-0244) TESTED IN GLASSHOUSE AND FIELD TRIALS.

Treatment	Formulation type	Composition	Trials[1]	% available ai
MK-0244-81 2 WP	Dry powder blend	ai, diluents, surfactants	GH 1,2; F 1-3	47
MK-0244-83 5 WG	Wettable granule	ai, solvents, carrier, surfactants	GH 1,2; F 1-3	> 95
MK-0244-85 5 SG	Soluble granule	ai, soluble diluents, surfactants	GH 1,2,3; F 1-4	> 95
MK-0244-86 5 SG	Soluble granule	ai, diluents, surfactants	GH 3; F 4	> 95
MK-0244-87 5 SG	Soluble granule	ai, diluents, surfactants	GH 3; F 4	> 95
MK-0244-88 5 SG	Soluble granule	ai, soluble diluents, surfactants	GH 3; F 4	> 95
MK-0244-49 0.16 EC	Emulsifiable concentrate	ai, solvents, surfactants	GH 1,2,3; F 1-4	> 95

[1]GH, Glasshouse; F, Field; numbers correspond to trial number (e.g., GH 1,2,3 = trials 1, 2, and 3 in the glasshouse).

combining all ingredients and stirring until all solids had dissolved as described previously (Jansson et al. 1996). The EC formulation (0.16 EC) and the dry powder blend contained 2.0-2.2% w/w of emamectin benzoate. The WG and SG formulations contained 4.8-5.2% w/w of emamectin benzoate.

Chemical availability, or the percentage of ai in solution within one hour after dissolving in water, was estimated for all formulations tested using methods described previously (Jansson et al. 1996). Estimates for percentages of available emamectin benzoate in solution that were > 95% could not be measured accurately based on the methods used.

Glasshouse Tests

Methods used in all glasshouse tests were similar to those described previously (Jansson et al. 1996). Three trials were conducted to compare the residual efficacy of the six solid formulations of emamectin benzoate with the EC formulation (Table 1). Formulations tested in each trial are given in Table 1. In all three trials, formulations of emamectin benzoate were applied to plants at two rates: the proposed field use rate (8.4 g ai/ha) and 1% of this rate (0.084 g ai/ha).

Residual efficacy of each formulation was evaluated by challenging neonates of three lepidopterous pests, tobacco budworm, *Heliothis virescens* (F.), beet armyworm, *Spodoptera exigua* (Hübner), and cabbage looper, *Trichoplusia ni* (Hübner). *Heliothis virescens* was tested on two-week old chickpea, *Cicer arietinum* cv. Burpee Garbanzo 5024, plants; *T. ni* was tested on two-week old cabbage, *Brassica oleracea* var. *capitata*

L. cv. Early Jersey Wakefield, plants; and *S. exigua* was tested on five-week old pepper, *Capsicum annuum* L. cv. Pimento, plants, two-week old sugarbeet, *Beta vulgaris* L. cv. USH-11, plants, or excised leaves of scarlet runner bean, *Phaseolus coccineum* L. Cuttings from scarlet runner bean were excised when plants were approximately 6-8 days old, placed in an Aquapic™ containing deionized water, and subsequently sprayed with the various formulations as described previously (Jansson et al. 1996).

Plants were sprayed with different formulations of emamectin benzoate using a track-sprayer system that delivered 153.2 liters/ha at 3.4 kg/cm^2 and at 3.5 km/h (Jansson et al. 1996). All formulations were applied in combination with a nonionic surfactant (0.0625%; Leaf Act 80A, PureGro Co., West Sacramento, CA). In all three trials, 100 plants for each species were treated with two rates of each formulation using a CO_2 track-sprayer system described previously (Jansson et al. 1996). Plants were air-dried after applications were made and then moved to a glasshouse (trials 1 and 2) for the duration of the experiment. In the third trial, plants were moved outdoors after they were air-dried. All plants were bottom watered to minimize wash-off of emamectin benzoate from foliage. Ten plants were randomly selected from each treatment on days 0, 4, 7, 10, 14, 17, and 21. One representative leaf was randomly excised from each plant and placed in water agar dishes. Approximately ten neonates were placed in each dish on each sample date; mortality was recorded after 96 hours.

High control mortality was found in the second trial. For this reason, an additional test was conducted using a miniature volume assay similar to that described previously (Jansson et al. 1998). Formulations 81, 83, 85 and the EC (49) were applied at two concentrations (4 and 20 ng/ml [ppb]) to foliage of scarlet runner bean, *Phaseolus coccineum* L., 'Pimento' pepper, and chickpea using an airbrush applicator and then challenged with neonate *S. exigua* (scarlet runner and pepper) and *H. virescens* (chickpea) using methods described previously (Jansson et al. 1998). Mortality of larvae was recorded on 0, 3, and 7 days after application (DAA). Approximately 100 neonates were tested per treatment combination per evaluation time.

Field Tests

Four field tests were conducted in 1994 and 1995 in Florida. Experimental formulations were compared with the EC formulation at the proposed use rate (8.4 g ai/ha). In all except the last field test, formulations were applied at 7- and 14-day intervals. Tests were conducted in Loxahatchee, FL, in two commercial cabbage, *B. oleracea* var *capitata* cv. Monument, fields; in Belle Glade, FL in a commercial celery, *Apium graveolens* L. cv. Florida 683 K-strain, field; and in Immokalee, FL, in a commercial bell pepper, *C. annuum* var. *annuum* L. cv. California Wonder, field. Formulations 81, 83, 85 and the EC (49) were tested in the first three trials (celery, pepper and one cabbage trial); formulations 85, 86, 87 and 88 were tested in the last trial on cabbage. All formulations were applied in combination with a nonionic surfactant (0.0625%; Leaf Act 80A, PureGro Co., West Sacramento, CA).

'Florida 683 K-strain' celery was transplanted 0.2 m apart in rows 0.6 m apart in a muck soil in Belle Glade, FL. Treatments were arranged in a randomized complete block design with four replications. Each plot was two rows by 7.7 m long. Treatments were applied on either three (14-day intervals) or six dates (7-day intervals) in November and December, 1994. Applications were made using a CO_2 backpack sprayer equipped with three equally-spaced (0.3 m) hollow disk/cone nozzles (D5-45). The sprayer delivered 467.3 liter per ha at 2.7 kg/cm^2. Numbers of *S. exigua* and *T. ni* larvae were recorded on five randomly selected plants per replicate on seven dates. Marketability was determined by harvesting the center 3.0 m from each row and recording the weight, size, and number of marketable celery stalks.

Two rows of 'California Wonder' bell pepper were transplanted into beds (1.2 m wide between centers) covered with plastic mulch in a light sandy soil in Immokalee, FL. Plants were spaced 0.3 m apart within rows 0.6 m apart. Treatments were arranged in a randomized complete block design with four replications. Each plot was one bed by 6.2 m long. Treatments were applied on either three (14-day intervals) or six dates (7-day intervals) between December, 1994 and January, 1995 using a CO_2 backpack sprayer system described previously. Numbers of southern armyworm, *S. eridania* (Cramer), larvae were recorded on six randomly selected plants per replicate on two dates. Percentage marketability was determined by harvesting the center 20 plants from each plot, and then dividing the number of marketable fruit by the total number of fruit per plot.

Four rows of 'Monument' cabbage were transplanted into 1.2 m beds in a sandy soil in Loxahatchee, FL. Plants were spaced 0.2 m apart within rows 0.3 m apart. Treatments were arranged in a randomized complete block design with four replications. Each plot was one bed by 4.7 m long. Treatments were applied on either three (14-day intervals) or six dates (7-day intervals) between December, 1994 and January, 1995 using a CO_2 backpack sprayer system described previously. Numbers of diamondback moth, *Plutella xylostella* (L.), larvae were recorded on five randomly selected plants per replicate on three dates. Damage ratings were recorded on five dates using a scale from 1 to 5 modified from Greene et al. (1969) where 1 = no damage and 5 = damage comparable to the nontreated control. Percentage marketability (damage rating ≤ 2) was determined based on the center 20 plants from each plot and evaluating each plant for unacceptable damage to the head.

In the fourth trial, transplants of 'Monument' cabbage were planted into two rows per bed (0.9 m) in Loxahatchee, FL in March, 1995. Plants were spaced 0.2 m apart in rows 0.3 m apart. Treatments were arranged in a randomized complete block design with four replications. Each plot was two beds wide by 7.7 m long. Treatments were applied on four dates (7-day intervals) between April and May using the CO_2 backpack sprayer system described previously. Numbers of *P. xylostella* larvae were recorded on five randomly selected plants per replicate on five dates. Damage ratings and percentage marketability were not recorded because ambient temperatures increased considerably at the end of the trial thereby reducing head formation.

Data Analysis

Data were analyzed using both nonparametric methods (Conover 1980) and least squares analysis of variance techniques (Zar 1984). Chemical availability of emamectin benzoate was compared among formulations by chi-square analysis (Conover 1980). Percentage mortality was transformed to the arcsine of the square root to normalize error variance. Means were separated by the Waller-Duncan *K*-ratio *t*-test (WDKR, Waller & Duncan 1969). Percentage data from field experiments were also transformed to the arcsine of the square root; all data from field studies were analyzed using standard analysis of variance techniques. Means were separated by Duncan's new multiple range test ($P = 0.05$) (SAS Institute 1990).

Results and Discussion

Percentage Availability of Emamectin Benzoate

Percentages of ai (emamectin benzoate) that completely dissolved into water after one hour and were then available for delivery differed ($X^2 = 30.2; P < 0.001$) among the

formulations tested. Most of the variation was attributable to a single formulation (81). The percentage of emamectin benzoate that was available in solution was considerably lower for formulation 81 (2WP; 47%) compared with all other formulations tested (> 95%) (Table 1).

Glasshouse Tests

In the first trial, all of the formulations tested were very effective and comparable (*K*-ratio = 100; WDKR) at killing both Lepidopteran targets when applied at the high rate (8.4 g ai/ha) on all dates (Tables 2 and 3). High levels of mortality (96-100%) were achieved up to 17 DAA for all formulations.

At the low rate (0.084 g ai/ha), differences in mortality of *S. exigua* larvae did not differ among formulations on most dates, although mortality achieved with formulation 83 was significantly lower than that produced by formulation 81 and 49 on 14 and 17 DAA (Table 2). Mortality of *H. virescens* did not differ among most formulations on most dates, albeit trends in the data suggested that the EC (49) was the least effective at controlling *H. virescens* at the low rate (0.084 g ai/ha) (Table 3).

In the second trial, the effectiveness of all four formulations at controlling both Lepidoptera was comparable at both rates applied (Tables 4 and 5). Despite high control mortality on certain dates, no differences in larval mortality were observed, even on dates when control mortality was acceptable (≤ 20%). In the miniature volume assay, mortality of *S. exigua* larvae on pepper and *H. virescens* larvae on chickpea did not differ among formulations on all dates at the high concentration (20 ng/ml) (Table 6). On clipped leaves of scarlet runner bean, formulations were comparable in their effectiveness at killing *S. exigua* on days 0 and 3 after application; however, on 7 DAA, formulation 83 was superior to formulation 81. All other formulations were comparable in their effectiveness at killing *S. exigua*. Formulations differed markedly when applied at the lower concentration (4 ng/ml) (Table 6). On pepper, most formulations did not differ on all three dates; formulation 81 was the least effective formulation on pepper. Formulations 83 and 49 were consistently the most effective formulations at controlling *H. virescens* on chickpea. None of the formulations was effective at controlling *S. exigua* on 3 and 7 DAA on scarlet runner bean when applied at 4 ng/ml. On day 0, mortality of *S. exigua* on plants treated with formulations 85 and 49 was higher than on those treated with formulations 81 and 83.

Mortality of *S. exigua* on scarlet runner bean was markedly lower than that observed on pepper at both concentrations of each formulation tested. We recognize that several factors (i.e., leaf structure, cuticle thickness, etc.) may account for these differences; however, excision of scarlet runner leaves may have reduced translaminar movement of emamectin benzoate into parenchyma tissue thereby affecting the reservoir of the toxicant inside foliage over time. Translaminar movement of avermectin insecticides is central to the prolonged residual efficacy observed in a variety of crops under glasshouse and field conditions (Jansson & Dybas 1997).

In the third trial, all formulations were comparable at controlling *S. exigua* on sugarbeet and *H. virescens* on chickpea when applied at the high rate (Tables 7 and 8). Effectiveness at controlling *T. ni* on cabbage differed among formulations, even at the high rate (Table 9). The EC formulation was consistently more effective at controlling *T. ni* than formulations 86 and 88 on days 7 to 14 after application. Formulations 85 and 87 were comparable to the EC on most dates; formulations 86 and 88 were consistently the least effective at controlling *T. ni*.

At the low rate, formulation 88 was consistently more effective at controlling *S. exigua* than most other experimental formulations, but did not differ from control achieved with the EC formulation on any evaluation date (Table 7). Formulations 85

TABLE 2. RESIDUAL EFFECTIVENESS OF DIFFERENT FORMULATIONS OF EMAMECTIN BENZOATE (MK-0244) AT CONTROLLING NEONATE *S. EXIGUA* ON PEPPER PLANTS IN THE GLASSHOUSE, TRIAL 1.

		% mortality					
		Infestation date, day after application[1]					
Formulation treatment	Rate, g ai/ha	0	4	7	10	14	17
MK-0244-081 2 WP	0.084	100.0(0.0)a	96.1(2.6)ab	92.8(3.6)a	69.2(11.3)b	59.7(7.2)b	54.7(10.9)bc
MK-0244-083 5 WG	0.084	100.0(0.0)a	90.0(5.5)b	78.4(6.6)b	63.7(9.1)b	26.7(10.2)c	41.4(12.8)cd
MK-0244-049 0.16 EC	0.084	100.0(0.0)a	88.9(6.0)b	52.8(8.2)c	74.1(7.4)b	62.1(11.5)b	67.7(8.6)b
MK-0244-081 2 WP	8.4	100.0(0.0)a	100.0(0.0)a	98.8(1.2)a	100.0(0.0)a	99.2(0.8)a	100.0(0.0)a
MK-0244-083 5 WG	8.4	100.0(0.0)a	100.0(0.0)a	97.1(2.3)a	100.0(0.0)a	100.0(0.0)a	95.6(1.9)a
MK-0244-049 0.16 EC	8.4	99.4(0.6)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	99.6(0.4)a	100.0(0.0)a
Nontreated check	—	60.1(9.4)b	54.0(7.0)c	19.5(7.7)d	36.3(9.5)c	14.1(3.8)c	36.0(7.2)d

[1]Means within the same column followed by the same letter are not significantly different by the Waller-Duncan *K*-ratio *t*-test (*K*-ratio = 100).

TABLE 3. RESIDUAL EFFECTIVENESS OF DIFFERENT FORMULATIONS OF EMAMECTIN BENZOATE (MK-0244) AT CONTROLLING NEONATE *H. VIRESCENS* ON CHICKPEA PLANTS IN THE GLASSHOUSE, TRIAL 1.

		% mortality					
		Infestation date, day after application[1]					
Formulation treatment	Rate, g ai/ha	0	4	7	10	14	17
MK-0244-081 2 WP	0.084	100.0(0.0)a	97.5(2.5)a	94.9(2.5)a	92.3(3.2)ab	96.4(2.6)a	99.1(0.9)a
MK-0244-083 5 WG	0.084	100.0(0.0)a	98.5(1.0)a	98.1(1.3)a	99.2(0.8)a	100.0(0.0)a	97.4(1.4)a
MK-0244-049 0.16 EC	0.084	100.0(0.0)a	84.5(6.7)b	81.9(6.0)b	90.7(3.9)b	94.1(3.1)a	96.9(1.6)a
MK-0244-081 2 WP	8.4	100.0(0.0)a	99.0(1.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a
MK-0244-083 5 WG	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a
MK-0244-049 0.16 EC	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	99.2(0.8)a
Nontreated check	—	50.0(9.8)b	28.8(6.0)c	25.1(5.5)c	48.5(8.0)c	30.1(10.0)b	59.5(10.0)b

[1]Means within the same column followed by the same letter are not significantly different by the Waller-Duncan *K*-ratio *t*-test (*K*-ratio = 100).

TABLE 4. RESIDUAL EFFECTIVENESS OF DIFFERENT FORMULATIONS OF EMAMECTIN BENZOATE (MK-0244) AT CONTROLLING NEONATE *S. EXIGUA* ON PEPPER PLANTS IN THE GLASSHOUSE, TRIAL 2.

		% mortality						
		Infestation date, day after application[1]						
Formulation treatment	Rate, g ai/ha	0	4	7	10	14	17	21
MK-0244-081 2 WP	0.084	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	98.7(1.3)a	97.2(2.8)a	99.4(0.6)	98.0(2.0)a
MK-0244-083 5 WG	0.084	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	98.2(1.2)	98.0(2.0)a
MK-0244-085 5 SG	0.084	100.0(0.0)a	100.0(0.0)a	98.8(1.2)a	98.5(1.5)a	99.0(1.0)a	98.5(1.5)	94.9(3.2)a
MK-0244-049 0.16 EC	0.084	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	97.0(1.8)a	100.0(0.0)a	99.4(0.6)	96.4(3.6)a
MK-0244-081 2 WP	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	99.2(0.8)	98.5(1.5)a
MK-0244-083 5 WG	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)	98.6(1.4)a
MK-0244-085 5 SG	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)	100.0(0.0)a
MK-0244-049 0.16 EC	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)	100.0(0.0)a
Nontreated check	—	61.8(9.1)b	66.9(7.5)b	16.7(9.2)b	0.0(0.0)b	69.0(10.3)b	70.9(10.9)	45.2(11.9)b

[1]Means within the same column followed by the same letter or no letter are not significantly different by the Waller-Duncan K-ratio t-test (K-ratio = 100).

TABLE 5. RESIDUAL EFFECTIVENESS OF DIFFERENT FORMULATIONS OF EMAMECTIN BENZOATE (MK-0244) AT CONTROLLING NEONATE *H. VIRESCENS* ON CHICKPEA PLANTS IN THE GLASSHOUSE, TRIAL 2.

		% mortality						
		Infestation date, day after application[1]						
Formulation treatment	Rate, g ai/ha	0	4	7	10	14	17	21
MK-0244-081 2 WP	0.084	100.0(0.0)a	97.8(2.2)a	93.2(6.8)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	60.2(21.8)b
MK-0244-083 5 WG	0.084	100.0(0.0)a	98.3(1.7)a	95.7(3.4)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	81.8(15.7)ab
MK-0244-085 5 SG	0.084	100.0(0.0)a	98.8(1.2)a	91.7(4.4)a	100.0(0.0)a	100.0(0.0)a	99.1(0.9)a	97.2(2.8)a
MK-0244-049 0.16 EC	0.084	100.0(0.0)a	98.8(1.2)a	98.8(1.2)a	100.0(0.0)a	100.0(0.0)a	96.9(2.1)a	100.0(0.0)a
MK-0244-081 2 WP	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a
MK-0244-083 5 WG	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a
MK-0244-085 5 SG	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.8)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a
MK-0244-049 0.16 EC	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a
Nontreated check	—	2.0(1.3)b	37.2(14.5)b	26.6(8.2)b	14.3(6.2)b	13.6(4.7)b	33.1(6.7)b	27.2(17.3)c

[1]Means within the same column followed by the same letter are not significantly different by the Waller-Duncan *K*-ratio *t*-test (*K*-ratio = 100).

TABLE 6. RESIDUAL EFFECTIVENESS OF DIFFERENT FORMULATIONS OF EMAMECTIN BENZOATE (MK-0244) AT CONTROLLING NEONATE *S. EXIGUA* ON PEPPER AND SCARLET RUNNER BEAN PLANTS AND NEONATE *H. VIRESCENS* ON CHICKPEA PLANTS IN A MINIATURE VOLUME BIOASSAY.

		% mortality								
		Infestation date, day after application[1]								
		Scarlet runner bean			Pepper			Chickpea		
Formulation treatment	Rate, ng/ml	0	3	7	0	3	7	0	3	7
MK-0244-081 2 WP	4	48.6b	0.0b	0.0c	100.0a	57.2bc	4.2d	42.4c	56.3c	13.6def
MK-0244-083 5 WG	4	37.4b	3.0b	0.0c	100.0a	45.9c	16.7cd	50.4b	88.4b	50.0abc
MK-0244-085 5 SG	4	85.4a	6.1b	0.0c	100.0a	53.5bc	51.7bc	62.0bc	50.6c	33.3cde
MK-0244-049 0.16 EC	4	75.6a	12.1b	9.7bc	100.0a	69.0b	9.5cd	69.5b	88.9b	43.8bcd
MK-0244-081 2 WP	20	100.0a	88.0a	13.0bc	100.0a	100.0a	96.3a	97.0a	100.0a	73.1ab
MK-0244-083 5 WG	20	100.0a	93.6a	62.5a	100.0a	100.0a	76.7ab	100.0a	100.0a	66.7abc
MK-0244-085 5 SG	20	100.0a	76.2a	31.2abc	100.0a	93.8a	69.8ab	100.0a	100.0a	77.8a
MK-0244-049 0.16 EC	20	100.0a	77.8a	37.3ab	100.0a	100.0a	100.0a	100.0a	100.0a	66.7abc
Nontreated check	—	3.3c	0.0b	0.0c	0.0b	0.0d	0.0d	0.0d	0.0d	0.0f

[1]Means within the same column followed by the same letter are not significantly different by the Waller-Duncan *K*-ratio *t*-test (*K*-ratio = 100).

TABLE 7. RESIDUAL EFFECTIVENESS OF DIFFERENT FORMULATIONS OF EMAMECTIN BENZOATE (MK-0244) AT CONTROLLING NEONATE *S. EXIGUA* ON PEPPER PLANTS IN THE GLASSHOUSE, TRIAL 3.

		% mortality				
		Infestation date, day after application[1]				
Formulation treatment	Rate, g ai/ha	0	4	7	10	14
MK-0244-085 5 SG	0.084	100.0(0.0)a	70.0(15.2)c	89.9(8.3)ab	42.7(15.1)c-e	47.2(16.3)d
MK-0244-086 5 SG	0.084	100.0(0.0)a	97.1(2.1)ab	97.4(1.7)a	54.4(16.6)cd	34.0(18.6)d
MK-0244-087 5 SG	0.084	100.0(0.0)a	29.5(13.3)d	30.4(9.6)c	27.1(5.8)de	63.9(13.7)a-d
MK-0244-088 5 SG	0.084	100.0(0.0)a	95.4(3.1)ab	90.6(4.7)ab	64.9(14.7)bc	53.1(24.1)b-d
MK-0244-049 0.16 EC	0.084	100.0(0.0)a	81.7(11.3)bc	88.3(5.0)b	62.9(14.5)bc	64.6(22.0)a-d
MK-0244-085 5 SG	8.4	100.0(0.0)a	100.0(0.0)a	98.0(2.0)ab	100.0(0.0)a	96.7(3.3)ab
MK-0244-086 5 SG	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	81.3(18.7)ab	100.0(0.0)a
MK-0244-087 5 SG	8.4	100.0(0.0)a	98.2(1.8)ab	98.5(1.5)ab	100.0(0.0)a	98.6(1.4)a
MK-0244-088 5 SG	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	87.1(12.9)a-c
MK-0244-049 0.16 EC	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	98.8(1.2)a
Nontreated check	—	35.8(8.9)b	19.7(8.4)d	21.8(14.6)d	22.5(7.6)e	25.3(8.4)d

[1]Means within the same column followed by the same letter are not significantly different by the Waller-Duncan *K*-ratio *t*-test (*K*-ratio = 100)

TABLE 8. RESIDUAL EFFECTIVENESS OF DIFFERENT FORMULATIONS OF EMAMECTIN BENZOATE (MK-0244) AT CONTROLLING NEONATE *H. VIRESCENS* ON CHICKPEA PLANTS IN THE GLASSHOUSE, TRIAL 3.

		% mortality			
		Infestation date, day after application[1]			
Formulation treatment	Rate, g ai/ha	0	4	10	14
MK-0244-085 5 SG	0.084	100.0(0.0)a	100.0(0.0)a	84.1(8.0)a	85.7(7.8)a-c
MK-0244-086 5 SG	0.084	98.2(1.8)a	100.0(0.0)a	82.6(11.5)a	79.4(12.9)bc
MK-0244-087 5 SG	0.084	100.0(0.0)a	100.0(0.0)a	98.3(1.7)a	95.3(3.0)ab
MK-0244-088 5 SG	0.084	100.0(0.0)a	97.5(2.5)a	90.4(6.2)a	68.7(17.8)bc
MK-0244-049 0.16 EC	0.084	98.0(2.0)a	96.9(3.1)a	80.0(20.0)a	72.0(8.8)cd
MK-0244-085 5 SG	8.4	100.0(0.0)a	100.0(0.0)a	96.7(3.3)a	100.0(0.0)a
MK-0244-086 5 SG	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a
MK-0244-087 5 SG	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a
MK-0244-088 5 SG	8.4	100.0(0.0)a	100.0(0.0)a	80.0(20.0)a	100.0(0.0)a
MK-0244-049 0.16 EC	8.4	100.0(0.0)a	100.0(0.0)a	96.4(2.2)a	100.0(0.0)a
Nontreated check	—	2.2(2.2)b	24.1(3.3)b	43.6(13.4)b	41.5(12.2)e

[1]Means within the same column followed by the same letter are not significantly different by the Waller-Duncan *K*-ratio *t*-test (*K*-ratio = 100).

TABLE 9. RESIDUAL EFFECTIVENESS OF DIFFERENT FORMULATIONS OF EMAMECTIN BENZOATE (MK-0244) AT CONTROLLING NEONATE *T. NI* ON CABBAGE PLANTS IN THE GLASSHOUSE, TRIAL 3.

		% mortality				
		Infestation date, day after application[1]				
Formulation treatment	Rate, g ai/ha	0	4	7	10	14
MK-0244-085 5 SG	0.084	23.0(8.6)cd	12.5(4.4)c	7.8(4.8)c	3.3(3.3)c	11.5(5.8)d
MK-0244-086 5 SG	0.084	17.7(7.9)d	7.5(4.8)c	2.2(2.2)c	4.0(4.0)c	12.3(7.4)d
MK-0244-087 5 SG	0.084	22.1(9.2)cd	5.9(3.7)c	0.0(0.0)c	5.0(3.3)c	12.9(5.0)d
MK-0244-088 5 SG	0.084	44.7(16.1)bc	2.3(2.3)c	9.7(5.2)c	1.5(1.5)c	3.1(1.9)d
MK-0244-049 0.16 EC	0.084	52.2(8.9)b	11.7(7.3)c	2.2(2.2)c	6.7(6.7)c	4.4(2.9)d
MK-0244-085 5 SG	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	88.7(7.4)ab	93.5(4.9)ab
MK-0244-086 5 SG	8.4	100.0(0.0)a	81.7(11.9)b	71.1(18.5)b	31.3(23.2)c	56.9(19.1)c
MK-0244-087 5 SG	8.4	100.0(0.0)a	95.8(4.2)ab	96.9(3.1)a	85.0(9.3)ab	80.5(11.1)bc
MK-0244-088 5 SG	8.4	100.0(0.0)a	100.0(0.0)a	77.8(11.1)b	76.5(10.8)b	48.4(21.0)c
MK-0244-049 0.16 EC	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a
Nontreated check	—	3.3(3.3)e	4.9(3.2)c	2.2(2.2)c	1.8(1.8)c	10.0(4.7)d

[1]Means within the same column followed by the same letter are not significantly different by the Waller-Duncan *K*-ratio *t*-test (*K*-ratio = 100).

and 87 were consistently the least effective at controlling this insect when applied at the low rate. All formulations were comparable in their effectiveness at controlling *H. virescens* at the low rate (Table 8). Effectiveness at controlling *T. ni* differed among formulations on day 0 after application (Table 9). The EC formulation was superior to formulations 85, 86, and 87 when applied at the low rate; formulation 88 was comparable to the EC on this date. The effectiveness of formulations at controlling *T. ni* did not differ on all remaining evaluation dates.

Field Trials

All of the field trials demonstrated that solid formulations of emamectin benzoate were as effective as the EC formulation at controlling Lepidoptera and reducing damage on vegetable crops (Table 10). In the first cabbage trial, mean numbers of *P. xylostella* larvae did not differ ($P < 0.05$) among formulations applied at either 7- or 14-day intervals on all dates, albeit only data for the peak population counts (7 days after the fifth application [7DAA5]) are shown (Table 10). No larvae were found per 5 plants in plots treated with all of the formulations of emamectin benzoate, whereas high larval pressure was observed on nontreated plants (146.5 larvae/5 plants). Similar results were found at harvest. Damage ratings did not differ among formulations (data not shown); all formulations resulted in 100% marketability of heads, whereas only 2.5% of heads were marketable in nontreated plots.

Similar results were found in the celery trial on all dates (although all data are not shown). All formulations were comparable at controlling lepidopterous pests and resulted in between 98 and 100% marketability of the crop (Table 10). On pepper, mean numbers of *S. eridania* larvae did not differ among formulations on all evaluation dates, albeit only two evaluation dates are shown (Table 10). Percentages of marketable fruit did not differ ($P < 0.05$) among most formulations; however, plants that were treated with formulation 81 at 7-day intervals and with formulation 83 at 14-day intervals produced lower percentages of marketable fruit (86.3%) than those treated with the EC formulation (49) at 7-day intervals (98.8%) (Table 10). All other formulations produced similar percentages of marketable fruit (88.8-95.0%).

The lower (although not consistently significant) efficacy of formulation 81 at controlling lepidopterous pests (as noted on pepper) concurs with an earlier report (Jansson et al. 1996), and is presumably due to the lower percentage availability of the active ingredient in solution. This formulation, however, was included in the present tests because it served as a lead solid formulation with a novel composition. Formulation 85 was subsequently designed from formulation 81, and as the data show, was as effective as the EC formulation in all of the tests conducted. The improved effectiveness of formulation 85, compared with formulation 81, was probably due, in part, to its higher percentage of available ai in solution.

The fourth field trial was conducted to determine the effects of slight differences in the composition of 5 SG formulations on field performance. All four of the formulations were comparable to the EC formulation at controlling Lepidoptera on cabbage in the field (Table 11).

As found in an earlier study (Jansson et al. 1996), excellent efficacy of all formulations of emamectin benzoate was found for up to 14-17 days after application when applied at a rate as low as 0.084 g ai/ha under glasshouse conditions. Similar results would not be expected in the field because avermectins are very susceptible to photodegradation. MacConnell et al. (1989) showed that the half-life of abamectin was < 10 h in light; the half-life for foliar dislodgeable residues of emamectin benzoate on celery was approximately 15 h (Merck, unpublished data).

TABLE 10. MEAN (± SEM) NUMBERS OF LARVAE PER SAMPLE UNIT AND PERCENTAGE MARKETABILITY ON THREE VEGETATIVE CROPS TREATED WITH DIFFERENT FORMULATIONS OF EMAMECTIN BENZOATE (MK-0244).

			Cabbage[1]		Pepper[1]			Celery[1]		
			Mean no. DBM[2]/5 plants		Mean no. SAW[3]/plant			Mean no. BAW[4]/plant		
Treatment	Rate, g ai/ha	Spray interval, days	7 DAA[5]5	% mark[6]	7 DAA[5]3	7 DAA[5]8	% mark[6]	7 DAA[5]2	7 DAA[5]6	% mark[6]
MK-0244-081 2 WP	8.4	7	0.0b	100.0a	0.0b	0.0b	86.3b	0.0b	0.0b	98.0a
MK-0244-081 2 WP	8.4	14	0.0b	100.0a	0.3b	0.0b	91.3ab	0.5b	0.0b	99.0a
MK-0244-083 5 WG	8.4	7	0.0b	100.0a	0.0b	0.0b	95.0ab	0.0b	0.0b	99.5a
MK-0244-083 5 WG	8.4	14	0.0b	100.0a	0.0b	0.0b	86.3b	0.0b	0.0b	99.0a
MK-0244-085 5 SG	8.4	7	0.0b	100.0a	0.0b	0.0b	93.8ab	0.0b	0.0b	99.0a
MK-0244-085 5 SG	8.4	14	0.0b	100.0a	0.3b	0.0b	88.8ab	0.3b	0.0b	99.5a
MK-0244-049 0.16 EC	8.4	7	0.0b	100.0a	0.0b	0.0b	98.8a	0.0b	0.0b	98.5a
MK-0244-049 0.16 EC	8.4	14	0.0b	100.0a	0.0b	0.0b	93.8ab	0.0b	0.0b	100.0a
Nontreated check	—	—	146.5a	2.5b	4.5a	3.0a	58.8c	2.3a	3.0a	18.5b

[1]Means within the same column followed by the same letter are not significantly different by Duncan's multiple range test ($P = 0.05$).
[2]DBM, diamondback moth.
[3]SAW, southern armyworm.
[4]BAW, beet armyworm.
[5]Sample date, days after application (DAA); e.g., 7 DAA 5 = seven days after the fifth application.
[6]Percentage marketability.

TABLE 11. MEAN (±SEM) NUMBERS OF *P. XYLOSTELLA* LARVAE PER FIVE PLANTS ON CABBAGE TREATED WITH DIFFERENT FORMULATIONS OF EMAMECTIN BENZOATE (MK-0244).

Formulation treatment	Rate, g ai/ha	Spray interval, days	Mean no. DBM[1]/5 plants[2] 7 DAA[3]1	7 DAA[3]2	7 DAA[3]3	7 DAA[3]4
MK-0244-085 5 SG	8.4	7	2.0b	2.3b	4.5b	1.3b
MK-0244-086 5 SG	8.4	7	13.0b	2.8b	0.8b	1.0b
MK-0244-087 5 SG	8.4	7	5.0b	1.8b	3.0b	1.0b
MK-0244-088 5 SG	8.4	7	4.0b	1.5b	2.3b	1.0b
MK-0244-049 0.16 EC	8.4	7	2.5b	1.3b	0.3b	0.0b
Nontreated check	—	—	31.0a	23.0a	16.8a	32.0a

[1]DBM, diamondback moth.
[2]Means within the same column followed by the same letter are not significantly different by Fisher's protected LSD ($P < 0.05$) (Zar 1984).
[3]As in Table 10.

The composition of pesticide formulations can affect their acute toxicity and safety to mammals (Hudson & Tarwater 1988). The acute oral toxicity of technical grade emamectin benzoate is about 70 mg/kg (rat) in an ingestion assay (Anomymous 1995). The acute oral LD50 of the 0.16 EC and 5 SG formulations are 2,646 and 1,516 mg/kg body weight (rat), respectively (Anonymous 1995, Merck, unpublished data). The 5 SG formulation is more toxic than the EC formulation because it is 2.5-fold more concentrated. However, other safety features (ocular and skin irritation in rabbit) are greatly improved with the 5 SG formulation compared with the 0.16 EC formulation (Anonymous 1995). These improvements in safety have reduced the potential risks of exposure during mixing and loading of the product into spray equipment and have improved its FIFRA classification from category 1 (DANGER) to category 3 (CAUTION). In addition to lowering risks of exposure, the 5 SG has additional attributes, including elimination of volatile organic solvents as a part of the composition of the formulation; its compatibility with water-soluble packaging to further reduce risks of exposure; and potentially reducing the need for plastic packaging thereby reducing the environmental burden.

These studies concurred with an earlier study that demonstrated that solid formulations of the benzoate salt of emamectin were effective at controlling lepidopterous pests on vegetable crops in the glasshouse and in the field (Jansson et al. 1996). More importantly, they helped to identify a 5 SG formulation with a delivery system that is novel for both avermectin chemistry as well as for the agrichemical industry (Merck, unpublished). The 5 SG formulation has been developed along with the 0.16 EC formulation for control of lepidopterous pests on a variety of vegetable crops and will soon be available commercially. Because of its compatibility with integrated pest management programs (Jansson & Dybas 1997), the new formulation of emamectin benzoate should be an important tool for control of lepidopterous pests in the future.

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