EFFICACY OF SOLID FORMULATIONS OF EMAMECTIN BENZOATE AT CONTROLLING LEPIDOPTEROUS PESTS

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ABSTRACT

Six solid formulations of emamectin benzoate (three impregnated powder blends, two dry powder blends, and one soluble granule) were compared with an emulsifiable concentrate (EC) formulation for their residual efficacy at killing tobacco budworm, *Heliothis virescens* (F.) (= *Helicoverpa virescens* (F.)), and beet armyworm, *Spodoptera exigua* (Hübner), in glasshouse tests. Two trials were conducted. Emamectin benzoate was applied to plants at two rates in each trial (8.4 and 0.084 g ai/ha in the first trial; and 8.4 and 0.84 g ai/ha in the second trial). The first trial was conducted in a glasshouse; in the second trial, plants were treated in the glasshouse and moved outdoors for the duration of the study.

In the first trial, all three impregnated powder blends, one dry powder blend, and the EC formulation were comparable in their effectiveness at controlling both targets when applied at the high rate (8.4 g ai/ha). At the low rate, efficacy at controlling *H. virescens* did not differ among formulations, whereas the two powder formulations provided the longest residual efficacy against *S. exigua*. In the second trial, one impregnated powder blend, two dry powder blends, a soluble granule, and the EC formulation were comparable in their effectiveness at killing both species up to 10 days after application when applied at the high rate (8.4 g ai/ha). At the low rate (0.84 g ai/ha), one powder formulation was consistently more effective at controlling *S. exigua*, whereas no formulation consistently outperformed all others at controlling *H. virescens.* Two field studies demonstrated that two dry powder blend formulations were very effective and comparable to the EC formulation at controlling *Helicoverpa zea* (Boddie), *Keiferia lycopersicella* (Walsingham), and *S. exigua* on tomato. These data demonstrate that solid formulations of emamectin benzoate have potential for control of Lepidoptera. The importance of a solid formulation for emamectin benzoate is discussed.

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

RESUMEN

La eficacia residual sobre el gusano cogollero del tabaco, *Heliothis virescens* (F.) (=*Helicoverpa virescens* (F.)) y el gusano de la remolacha, *Spodoptera exigua* Hübner, de seis formulaciones sólidas de benzoato de emamectin (tres mezclas de polvos impregnados, dos mezclas de polvo seco y un granulado sólido) fue comparada con la de un concentrado emulsionable (CE) en ensayos de invernadero. Dos ensayos fueron realizados. El benzoato de emamectin fue aplicado a las plantas a dos dosis en cada ensayo (8.4 y 0.084 g ai/ha en el primer ensayo, y 8.4 y 0.84 g ai/ha, en el segundo). El primer ensayo fue llevado a cabo en un invernadero; en el segundo ensayo las plantas fueron tratadas en el invernadero y se mantuvieron fuera durante el resto del estudio.

En el primer ensayo, las efectividades de las tres mezclas de polvos impregnados, una mezcla de polvo seco y la EC fueron comparables en su efectividad para controlar a los dos sujetos cuando se aplicaron a alta dosis (8.4 g ai/ha). A la dosis baja, la eficacia para controlar *H. virescens* no difirió entre las formulaciones, mientras que las dos formulaciones de polvo mostraron la más larga eficacia residual contra *S. exigua*. En el segundo ensayo, una mezcla de polvo impregnado, dos mezclas de polvos secos, un granulado soluble y la formulación del CE tuvieron efectividades comparables contra ambas especies hasta los 10 días después de la aplicación, cuando se aplicaron a la dosis alta (8.4 g/ai/ha). A la dosis baja (0.84 g ai/ha), una formulación de polvo fue consistentemente más efectiva en el control de *S. exigua*, y ninguna formulación fue más efectiva que las otras controlando *H. virescens*. Dos estudios de campo demostraron que dos mezclas de polvo seco fueron muy efectivas y comparables con la formulación de CE en el control de *Helicoverpa zea* (Boddie), *Keiferia lycopersicella* (Walshingham) y *S. exigua* en el tomate. Estos datos demuestran que las formulaciones sólidas de benzoato de emamectin tienen potencial para el control de Lepidoptera. Se discute la importancia de una formulación para el benzoato de emamectin.

Avermectins are a family of 16-membered lactone natural product compounds produced by the soil microorganism, *Streptomyces avermitilis* MA-4680 (NRRL 8165), which was isolated in culture at the Kitasato Institute from a soil sample taken from Kawana Ito City, Shizuoka Prefecture, Japan. The major component of the fermentation is avermectin B_1, a mixture of B_1a (80%) and B_1b (20%) (Dybas et al. 1989). The discovery, structures, environmental fate, spectrum of activity, and applications for control of arthopods have been reviewed (Campbell et al. 1984, Dybas 1989, Lasota & Dybas 1991). Abamectin, the common name assigned to avermectin B_1, is currently sold commercially for control of mites and certain insect pests on a range of ornamental and horticultural crops in about 50 countries worldwide.

Emamectin [4”-epi-methylamino-4”-deoxyavermectin B_1 hydrochloride salt (MK-0243)] is a semisynthetic derivative of abamectin (Dybas 1988). This second generation avermectin was shown to be up to 1,500-fold more potent against armyworm species, e.g., beet armyworm, *Spodoptera exigua* (Hübner), and 105- and 43-fold more toxic to tomato fruitworm, *Helicoverpa zea* (Boddie), and tobacco budworm, *Heliothis virescens* (Guenee), larvae, respectively, than abamectin (Dybas & Babu 1988, Dybas et al. 1989, Mrozik et al. 1989, Trumble et al. 1987). This compound was also 1,720-, 884-, and 268-fold more potent against *S. eridania* (Cramer) than methomyl, thiodicarb, and fenvalerate, respectively (Dybas & Babu 1988). The benzoate salt of this compound (MK-0244; PROCLAIM[R]), was subsequently found to be more stable than the hydrochloride salt and is currently being developed for control of Lepidoptera on a variety of horticultural crops worldwide. Excellent efficacy at unprecedented use rates (8.4 g ai/ha) has been demonstrated against numerous Lepidoptera on a variety of crops in the field (Jansson & Dybas 1996, Jansson & Lecrone 1991, Lasota & Dybas 1991, Leibee et al. 1995).

Minor changes in the constituents of formulations may have marked effects on product efficacy (Hartley & Graham-Bryce 1980). Edwards et al. (1994) showed that formulation type may affect the behavior of arthropods and concomitantly affect product efficacy. Historically, solid formulations of avermectins have been less effective at controlling arthropods than liquid formulations. For this reason, most studies on emamectin benzoate conducted to date used an emulsifiable concentrate (EC) formulation of this semisynthetic derivative of avermectin. No studies have been conducted to compare efficacy of alternative formulations of emamectin benzoate at controlling arthropods.

In addition, choice of formulation type and ingredients may significantly affect the acute toxicity of a formulation (Hudson & Tarwater 1988). Because of the scrutiny placed on emulsifiable concentrate formulations by the Environmental Protection Agency, many agrichemical companies have developed solid formulations for use in water soluble packaging. Such formulations result in lower worker exposure during the mixing and loading of pesticides into spray equipment. This paper presents data from glasshouse and field studies on the efficacy of novel solid formulations of emamectin benzoate against several economically important lepidopterous pests.

MATERIALS AND METHODS

Formulations Tested

Formulations tested were of four types: impregnated powder blends, dry powder blends, a soluble granule, and the EC formulation (Table 1). Impregnated powder blends (formulations 77, 78, and 79) were prepared by dissolving technical grade material of emamectin benzoate (Merck & Co., Rahway, NJ) in the solvent and spraying the solution onto a heated carrier, followed by the addition of other ingredients, and then blending until homogenous. These three formulations utilized different solvents and carriers. Dry powder blends (formulations 80 and 81) were prepared by combining all ingredients and then blending until homogenous. These two formulations differed in the diluents and surfactants. The soluble granule (formulation 82) was prepared by dissolving emamectin benzoate and a surfactant in a molten matrix. This mixture was blended until homogenous, cooled, and comminuted in a Waring blender; flakes passing through a 10-mesh screen were tested. The EC formulation (formulation 49) was prepared by combining all ingredients and stirring until all solids had dissolved. All formulations, including the EC formulation (0.16 EC), contained 2.0-2.2% w/w of emamectin benzoate.

Solubility and pH Tests

An experiment was conducted to determine the percentage of emamectin benzoate in each formulation that dissolved in water. A subsample (1.0 g) of each solid formulation was added to deionized water (50 ml). Two aliquots (1 ml each) were removed from the solution after about 0 min and 1 h. The solution was not agitated between the two sample periods. Aliquots were transferred to volumetric flasks (25 ml), diluted with methanol (24 ml), and sonicated. Aliquots were drawn from this solution and centrifuged. The supernatant (10 *u*l samples) was then analyzed by HPLC with the following specifications: Zorbax C18 column (15 cm $\times$ 3.2 mm) run at 1 ml/min at 30°C with a wavelength of 245 nm and a 80:20:0.8 mobile phase (acetonitrile:water: etha-

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

Treatment	Formulation type	Composition	pH	Trials[1]	Avail. ai., %
MK-0244-77	Impregnated powder blend	A.I., solvents, carrier, surfactants	10.3	GH 1	95
MK-0244-78	Impregnated powder blend	A.I., solvents, carrier, surfactants	5.1	GH 1	93
MK-0244-79	Impregnated powder blend	A.I., solvents, carrier, surfactants	5.8	GH 1,2	94
MK-0244-80	Dry powder blend	A.I., diluents, surfactants	10.0	GH 1,2; F 1,2	79
MK-0244-81	Dry powder blend	A.I., diluents, surfactants	6.6	GH 2; F 1,2	47
MK-0244-82	Soluble granule	A.I., surfactants matrix	6.0	GH 2	99
MK-0244-49	Emulsifiable concentrate	A.I., solvents, surfactants		GH 1,2; F 1,2	100

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

nolamine, respectively). The chemical availability of emamectin benzoate was then calculated by the following:

$$\% \text{ available} = (Q_1/Q_0) \times 100$$

where Q_0 and Q_1 are the amount of emamectin benzoate recorded after 0 min and 1 h, respectively.

pH was determined from a 1:50 suspension of each solid formulation in deionized water using a pH meter.

Glasshouse Tests

Two trials were conducted to compare the residual efficacy of the six solid formulations of emamectin benzoate with the EC formulation. The first trial was conducted in the glasshouse. In the second trial, plants were treated with the different formulations in the laboratory and then moved between the glasshouse and the outdoors daily for the duration of the experiment. Plants were kept outdoors on clear days, but were held indoors on cloudy and rainy days and were held indoors each evening to minimize the effects of rain splash and dew on foliar residues.

The formulations that were tested in the two trials are listed in Table 1. The residual efficacy of these formulations was evaluated using two Lepidopteran targets, the tobacco budworm, *H. virescens,* and the beet armyworm, *S. exigua*. *Heliothis virescens* was tested on two-week old chickpea (*Cicer arietinum* cv. Burpee Garbanzo 5024) plants and *S. exigua* was tested on five-week old pepper (*Capsicum annuum* L. cv. Pimento) plants.

In the first trial, the recommended field use rate (8.4 g ai/ha) and 1% of this rate (0.084 g ai/ha) of emamectin benzoate were applied to plants for each of four formulations (77, 78, 79, and 80) and the EC formulation (49). In the second trial, formulation batches 79 and 80 were retested along with two additional formulations (81 and 82), and the EC formulation. Rates tested were the recommended field use rate (8.4 g ai/ha) and 10% of this rate (0.84 g ai/ha); the lower rate was increased (compared with trial 1) because of the increased ultraviolet radiation outdoors. In both trials, non-treated control plants were sprayed with water only.

In both trials, 100 plants for each species were treated with two rates of each formulation using a CO_2 track-sprayer system equipped with two disc-cone ceramic albuz red drop nozzles (Teejet [R] cone type, model D2-25) that delivered approximately 153.2 liters/ha at a pressure of 128 kg/cm^2 and a speed of 3.5 km/h. Plants were arranged beneath the track sprayer to ensure thorough coverage of spray materials. Plants were air-dried after applications were made and then moved to the glasshouse. 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, 1, 4, 7, 10, 14, and 21. One representative leaf was randomly excised from each plant and placed on the surface of water agar in petri dishes (9 cm diam). Ten neonate larvae were placed on each leaf on each sample date (n = 100 larvae per treatment per sample date); mortality was recorded after 96 hours.

Field Tests

Two field trials were conducted on tomato in 1994 with formulations 80 and 81. Formulations were compared with the EC formulation and chemical standards at recommended field rates. Emamectin benzoate treatments were applied at 7- and 14-day intervals, whereas the chemical standards were only applied at 7-day intervals. One trial was conducted in San Quintin, Baja California, Mexico in a commercial tomato, *Lycopersicon esculentum* Mill. var. UC-82, field. The second trial was conducted in Apex, North Carolina in a 'Better Boy' tomato field.

In Mexico, tomatoes were direct seeded in two rows on 1.5 m raised beds (two rows per bed) that were drip-irrigated and covered with plastic mulch. Treatments were arranged in a randomized complete block design with four replications. Each plot was 3.1 m across by 9.3 m long. A 1 m buffer of nontreated plants separated replicates. Treatments were applied on either 3 (14-day intervals) or 6 dates (7 day intervals) in July and August, 1994. Applications were made using a CO_2 backpack sprayer with a boom width (1.5 m) that ranged across each bed and equipped with four equally-spaced hollow cone disk/core nozzles (D-7/25). The sprayer delivered approximately 750 liter/ha at a pressure of 1.7 kg/cm^2. Lambda cyhalothrin (Karate 1 EC, Zeneca Ag Products, Wilmington, DE) was included (44 g ai/ha) as the chemical standard.

Beet armyworm, *S. exigua,* and tomato pinworm, *Keiferia lycopersicella* (Walsingham), damage was assessed after the fourth and sixth applications. On the first evaluation date, 100 fruit from the center two rows per plot were randomly selected and examined for surface damage (armyworm) and small tunnels (pinworm). At final harvest, all fruit in the center 6.2 m section per plot were picked and evaluated for damage and marketability. The percentage of fruit damaged by each pest was recorded.

In North Carolina, tomatoes were transplanted in single lines on raised beds (1.5 m across). Treatments were arranged in a randomized complete block design with four replications. Each plot was 1.5 m across by 6.2 m long. A single row of 'Silver Queen' sweet corn was planted midway between rows as a buffer to separate treatments. Treatments were applied on either 3 (14-day intervals) or 6 dates (7 day intervals) in July and August, 1994. Applications were made using a CO_2 backpack sprayer with a boom width (1.5 m) that ranged across each bed, and equipped with three equally-spaced hollow cone disk/core nozzles (D-3/25). The sprayer delivered 560 liters/ha at a pressure of 2.9 kg/cm^2. Methomyl (500 g ai/ha) (Lannate L, DuPont Agricultural Products., Wilmington, DE) and permethrin (112 g ai/ha) (Ambush 2E, Zeneca Ag Products, Wilmington, DE) were included as chemical standards. As in Mexico, the incidence of fruit damage was determined in each plot, except that damage was caused primarily by tomato fruitworm, *Helicoverpa zea* (Boddie). Damage was estimated on August 19, when fruit first reached maturity, and again on August 27 by picking and visually inspecting all ripe fruit. On September 2, all remaining fruit were harvested from the middle 4.6 m of each plot. Each harvested fruit was visually inspected and classified as either damaged by fruitworms or marketable. All damaged fruit were cut open and inspected to identify the pest responsible for damage. Percentages were recorded based on total weight of harvested fruit per date.

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 and analyzed using standard analysis of variance techniques (Zar 1984). Means were separated by Fisher's protected LSD ($P < 0.05$).

Results and Discussion

Solubility Test

Chemical availability differed among the seven formulations tested ($X^2 = 23.7$; df = 6; $P < 0.05$). Six of the seven formulations resulted in high estimates of availability (79-99%) of emamectin benzoate which did not differ ($X^2 = 3.1$; df = 5; $P > 0.05$) among formulations. One of the formulations (81) was markedly lower in availability (47%) of emamectin benzoate than all other formulations and accounted for most of the variation among formulations (Table 1).

Glasshouse Tests

Trial 1. 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, except day 21 when formulation 77 was inferior to formulations 80 and 49 at controlling *H. virescens* (Tables 2 and 3). High levels of mortality (95-100%) were achieved up to 21 days after application for all formulations.

At the low rate (0.084 g ai/ha), differences in mortality of *S. exigua* larvae among formulations were noticeable by day 4 (Table 2). On days 4, 7, and 10, formulation 80 was superior to all other formulations at killing *S. exigua*. On day 14, formulations 79, 80 and 49 were superior to formulations 77 and 78 at controlling *S. exigua*. On day 21, formulations 80 and 49 were superior to 77 and 78.

Mortality of *H. virescens* did not differ among most formulations on days 0-4 after application when formulations were applied at the low rate (0.084 g ai/ha) (Table 3). On the remaining evaluation dates, no single formulation consistently outperformed all other formulations at killing this pest. On day 7, mortality of *H. virescens* was greater on plants treated with formulations 79 and 49 than on those treated with formulations 77 and 80. On day 10, mortality was greater on plants treated with formulations 77, 78, and 79 than on those treated with formulation 80. On day 14, mortality was highest on plants treated with formulation 78 followed in decreasing order by those treated with formulations 77, 79, 80, and 49. On day 21, mortality did not differ (*K*-ratio = 100; WDKR) among most formulations.

In general, these data showed that all formulations were comparable in their residual efficacy at controlling both Lepidoptera under glasshouse conditions when applied at the proposed field use rate (8.4 g ai/ha). At the lower rate, formulation 80 was consistently the most effective formulation at controlling *S. exigua* followed by formulation 79, whereas none of the formulations were consistently superior at controlling *H. virescens*, although trends in the data suggested that formulation 79 was most effective (although not consistently significant) at controlling this pest. For these reasons, formulations 80 and 79 were selected for advanced testing in trial 2.

Trial 2. Differences in the residual efficacy of emamectin benzoate formulations were also observed when the plants were sprayed indoors and moved outdoors. At the high rate (8.4 g ai/ha), mortality of *S. exigua* and *H. virescens* did not differ (*K*-ratio = 100; WDKR) among formulations up to day 10 (Tables 4 and 5). On day 14, higher mortality of *S. exigua* was found on plants treated with formulation 80 than on those treated with formulation 82. On day 21, higher mortality of *S. exigua* was found on plants treated with formulations 80, 82, and 49 than on those treated with other formulations. On days 14 and 21, higher mortality of *H. virescens* was found on plants treated with formulations 80 and 49 than on those treated with other formulations.

At the low rate (0.84 g ai/ha), formulation 82 was least effective at controlling *S. exigua* on day 4; all other formulations resulted in comparable levels of mortality (Ta-

TABLE 2. MEAN (± SEM) PERCENTAGE MORTALITY OF *S. EXIGUA* LARVAE ON PEPPER PLANTS TREATED WITH DIFFERENT FORMULATIONS OF EMAMECTIN BENZOATE IN THE GLASSHOUSE, TRIAL 1.

		Days after Application[1]						
Formulation	Rate, g ai/ha	0	1	4	7	10	14	21
MK-0244-077	0.084	100.0(0.0)a	100.0(0.0)a	70.7(9.1)c	57.6(5.1)d	16.3(3.2)e	54.4(9.7)c	81.6(5.4)cd
MK-0244-078	0.084	100.0(0.0)a	100.0(0.0)a	88.4(4.0)b	60.2(7.0)cd	26.3(4.7)de	46.5(10.1)c	66.0(8.1)d
MK-0244-079	0.084	100.0(0.0)a	100.0(0.0)a	91.3(3.7)b	69.9(8.9)c	73.1(3.9)c	93.8(3.8)ab	89.9(6.2)bc
MK-0244-080	0.084	100.0(0.0)a	99.1(0.9)a	100.0(0.0)a	82.6(6.0)b	87.1(5.2)b	91.8(2.2)b	96.2(3.0)ab
MK-0244-049	0.084	100.0(0.0)a	100.0(0.0)a	90.6(3.6)b	68.8(6.7)c	68.6(5.4)c	98.1(1.9)ab	92.9(7.1)ab
MK-0244-077	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	98.8(0.8)a	98.2(1.8)a	97.9(1.5)ab	99.3(0.7)ab
MK-0244-078	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	99.4(0.6)a	100.0(0.0)a	99.1(0.6)ab
MK-0244-079	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	98.9(0.8)a	99.3(0.7)a	100.0(0.0)a
MK-0244-080	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	99.3(0.7)a	98.9(1.1)a	100.0(0.0)a	100.0(0.0)a
MK-0244-049	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	99.6(0.4)a	99.6(0.4)a	100.0(0.0)a	99.7(0.3)ab
Nontreated check	—	9.3(3.1)b	22.0(5.0)b	16.9(6.3)d	7.0(1.9)e	40.3(8.6)d	18.1(6.1)d	53.9(6.9)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; Waller & Duncan 1969).

TABLE 3. MEAN (± SEM) PERCENTAGE MORTALITY OF *H. VIRESCENS* LARVAE ON CHICKPEA PLANTS TREATED WITH DIFFERENT FORMULATIONS OF EMAMECTIN BENZOATE IN THE GLASSHOUSE, TRIAL 1.

		Days after Application[1]						
Formulation	Rate, g ai/ha	0	1	4	7	10	14	21
MK-0244-077	0.084	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	95.1(1.9)c	96.6(5.8)abc	96.4(1.9)ab	49.6(7.7)cd
MK-0244-078	0.084	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	96.8(1.5)bc	95.5(2.3)bc	100.0(0.0)a	41.8(4.1)d
MK-0244-079	0.084	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	99.2(0.8)ab	97.2(1.4)ab	52.9(5.2)cd
MK-0244-080	0.084	100.0(0.0)a	100.0(0.9)a	97.6(1.9)b	84.8(2.5)d	87.5(4.2)d	93.9(2.6)bc	44.4(4.9)cd
MK-0244-049	0.084	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	98.8(1.2)ab	92.2(2.6)cd	89.1(4.4)c	57.2(4.3)c
MK-0244-077	8.4	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	95.2(2.2)b
MK-0244-078	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	99.2(0.8)ab	100.0(0.0)a	98.4(1.1)ab
MK-0244-079	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	96.5(2.4)ab
MK-0244-080	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-0244-049		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	—	0.0(0.0)b	11.1(3.9)b	2.4(0.5)c	19.6(5.6)e	7.4(4.4)e	15.6(3.7)d	9.9(3.3)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; Waller & Duncan 1969).

ble 4). On days 7, 10, and 14, formulation 80 was consistently the most effective (although not consistently significant) formulation at killing *S. exigua*. Formulations 82 and 49 were the least effective formulations on these days. On day 21, mortality was highest on plants treated with formulation 49 followed by those treated with formulations 80, 81, 82, and 79.

Mortality of *H. virescens* did not differ among most formulations applied at the low rate (0.84 g ai/ha) up to day 4 (Table 5). Between days 7 and 21, no consistent differences in mortality of *H. virescens* were noted among formulations.

Data from the second trial concurred with those from the first trial and showed that all formulations were comparable in their residual efficacy at controlling *S. exigua* at the recommended field use rate (8.4 g ai/ha). Formulations were comparable in their efficacy at controlling *H. virescens* at this rate on most dates except days 14 and 21, when formulation 80 was found to be superior to most other formulations tested. At the lower rate, formulation 80 was consistently the most effective formulation at controlling *S. exigua* followed by formulations 79 and 81 (through day 14). As found in the first trial, none of the formulations were consistently superior at controlling *H. virescens* at the low rate.

Field Trials

Two dry powder blend formulations (80 and 81) were selected for field testing based on their performance in the glasshouse and on their compositions. Both field trials demonstrated that solid formulations of emamectin benzoate were as effective as the EC formulation at reducing fruit damage from Lepidoptera on tomato (Table 6). In Mexico, tomato pinworm damage did not differ ($P > 0.05$) among most chemical treatments on both dates. On the first evaluation date, damage was significantly lower on plants treated with formulation 81 applied at 7 day intervals, the EC formulation applied at 7-and 14-day intervals, and formulation 80 applied at 7-day intervals than on those treated with formulation 81 at 14-day intervals and on those treated with the chemical standard, lambda cyhalothrin (Table 6). On the second evaluation date, damage from tomato pinworm did not differ ($P > 0.05$) among all chemical treatments. Beet armyworm damage did not differ ($P > 0.05$) among most chemical treatments on both evaluation dates. On the first evaluation date, damage was highest on plants treated with formulation 81 at 14-day intervals; on the second evaluation date, damage was highest on plants treated with lambda cyhalothrin and on those treated with formulation 81 at 7-day intervals. Harvest data showed that formulation 80 applied at 7- and 14-day intervals, formulation 81 applied at 7-day intervals, and the EC formulation applied at 7- and 14-day intervals were the most effective treatments at increasing percentages of marketable fruit (Table 6). Formulation 81 applied at 14-day intervals and the chemical standard, lambda cyhalothrin, produced the lowest percentages of marketable fruit.

In North Carolina, all formulations and the chemical standards were effective at reducing fruit damage from *H. zea*. Percentage fruit damage did not differ among chemical treatments on the first harvest date (Table 6). Percentage of damaged fruit differed ($P < 0.05$) among chemical treatments on the second harvest date. Damage was lowest on plants treated with formulation 80 at 7-day intervals, which did not differ from those on plants treated with permethrin at 7-day intervals, the EC formulation (49) at 7- and 14-day intervals, and formulation 81 at 7-day intervals. Damage was highest on plants treated with formulation 81 at 14-day intervals. On the third harvest date, superior efficacy was observed on plants treated with formulation 80, the EC, and permethrin at 7-day intervals. Lower efficacy (although not consistently

TABLE 4. MEAN (± SEM) PERCENTAGE MORTALITY OF *S. EXIGUA* LARVAE ON PEPPER PLANTS TREATED WITH DIFFERENT FORMULATIONS OF EMAMECTIN BENZOATE IN THE GLASSHOUSE, TRIAL 2.

		Day after Application[1]						
Formulation	Rate, g ai/ha	0	1	4	7	10	14	21
MK-0244-079	0.84	100.0(0.0)a	100.0(0.0)a	97.8(1.7)ab	74.7(9.7)b	85.6(4.5)b	25.2(6.1)de	2.6(1.3)ef
MK-0244-080	0.84	100.0(0.0)a	100.0(0.0)a	99.5(0.5)ab	96.8(2.5)a	97.9(1.4)a	47.8(5.2)c	19.1(6.1)cd
MK-0244-081	0.84	97.6(1.8)b	99.2(0.8)a	95.1(3.4)ab	85.7(5.0)b	81.4(5.9)b	38.8(8.0)cd	14.3(6.4)cde
MK-0244-082	0.84	100.0(0.0)a	100.0(0.0)a	82.6(5.2)c	62.6(4.1)c	65.0(6.2)c	23.6(4.9)def	9.6(4.0)def
MK-0244-049	0.84	100.0(0.0)a	100.0(0.0)a	95.1(2.6)b	58.3(11.2)c	64.3(7.8)c	15.6(4.8)f	24.5(10.4)c
MK-0244-079	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	97.5(1.3)a	99.4(0.6)a	94.3(3.5)ab	68.1(9.1(b)
MK-0244-080	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	90.2(6.0)a
MK-0244-081	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	97.3(1.4)a	100.0(0.0)a	96.0(2.0)ab	76.8(5.1)b
MK-0244-082	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	99.4(0.6)a	98.0(0.8)a	88.7(2.9)b	92.8(2.2)a
MK-0244-049	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	95.8(1.6)ab	95.1(1.2)a
Nontreated check	—	17.64(4.4)c	55.1(8.5)b	40.3(9.1)d	8.3(1.8)d	22.3(4.4)d	17.7(3.5)ef	2.5(2.5)f

[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; Waller & Duncan 1969).

TABLE 5. MEAN (± SEM) PERCENTAGE MORTALITY OF H. VIRESCENS LARVAE ON CHICKPEA PLANTS TREATED WITH DIFFERENT FORMULATIONS OF EMAMECTIN BENZOATE IN THE GLASSHOUSE, TRIAL 2.

Formulation	Rate, g ai/ha	Day after Application[1] 0	1	4	7	10	14	21
MK-0244-079R001	0.84	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	89.7(3.0)cd	86.9(7.0)cd	53.5(4.6)d	49.7(7.1)c
MK-0244-080A001	0.84	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	96.4(1.9)ab	80.5(4.1)e	53.5(6.0)d	49.1(7.3)c
MK-0244-081C001	0.84	100.0(0.0)a	36.3(6.3)b	96.8(1.7)a	88.1(4.6)d	82.6(6.0)de	29.3(6.3)f	28.4(5.5)d
MK-0244-083E001	0.84	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	95.8(1.4)bc	95.0(1.7)bc	40.2(8.1)de	32.5(6.4)d
MK-0244-049C001	0.84	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	97.1(1.5)ab	97.5(1.8)ab	33.6(5.9)ef	55.4(6.8)c
MK-0244-079R001	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	97.6(1.2)ab	99.0(1.0)ab	86.3(3.0)b	82.1(3.6)b
MK-0244-080A001	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	99.3(0.7)ab	98.6(1.0)a	100.0(0.0)a
MK-0244-081C001	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	99.1(0.9)ab	98.4(1.6)ab	86.2(2.7)b	81.6(5.0)b
MK-0244-083E001	8.4	100.0(0.0)a	100.0(0.0)a	100.0(0.0)a	98.2(1.8)ab	100.0(0.0)a	74.6(4.5)c	92.1(2.7)b
MK-0244-049C001	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	100.0(0.0)a
Nontreated check	—	18.0(7.5)b	12.9(2.9)c	9.2(5.1)c	7.5(2.6)e	3.4(1.7)f	2.7(1.4)g	7.7(2.8)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; Waller & Duncan 1969).

TABLE 6. MEAN (± SEM) PERCENTAGE DAMAGE OF TOMATO FRUIT BY LEPIDOPTERA ON PLANTS TREATED WITH DIFFERENT FORMULATIONS OF EMAMECTIN BENZOATE IN TWO FIELD TRIALS IN 1994.

Treatment		Rate, g ai/ha	Application Interval, d	% Damaged Fruit, Mexico[1]				% Damaged Fruit, North Carolina[1]			
				PWI[2]	PW2[2]	SP1[3]	SP2[3]	% Mark	19 Aug.	27 Aug.	12 Sept.
MK-0244-080	2 WP	8.4	7	4.5c	0.0b	8.0c	0.6c	91.4a	1.2a	1.4a	0.0a
MK-0244-080	2 WP	8.4	14	6.0bc	0.5b	10.9bc	1.8bc	87.3abc	8.6a	8.8bc	6.9b
MK-0244-081	2 WP	8.4	7	5.0c	0.5b	9.9c	3.9b	86.2abc	5.0a	4.0abc	8.9b
MK-0244-081	2 WP	8.4	14	10.0b	0.5b	16.2b	2.5bc	81.3c	10.0a	10.3c	3.8ab
MK-0244-049	0.16 EC	8.4	7	5.0c	0.0b	7.6c	3.1bc	89.4ab	3.4a	2.9ab	0.0a
MK-0244-049	0.16 EC	8.4	14	4.0c	0.5b	11.6bc	2.4bc	86.0abc	6.2a	3.2abc	6.7b
λ-Cyhalothrin	1 EC	44.0	7	7.0b	1.0ab	12.2bc	4.7b	83.1bc			
Permethrin	2 EC	112.0	7						4.0a	1.9ab	0.0a
Methomyl	L	500.0	7						2.5a	6.5bc	4.8b
Nontreated check		—	—	15.0a	2.0a	28.0a	10.6a	61.4d	26.6b	47.7d	40.2c

[1]Means within the same column followed by the same letter are not significantly different by Fisher's LSD ($P < 0.05$) (Zar 1984).
[2]Tomato pinworm damage on 8 and 22 Sept. (PW1 and PW2, respectively).
[3]Beet armyworm damage on 8 and 22 Sept. (SP1 and SP2, respectively).

significant) was found on plants treated with formulation 81 at 7- and 14-day intervals, formulation 80 at 14-day intervals, the EC at 14-day intervals, and methomyl at 7-day intervals.

These studies demonstrated that several solid formulations of the benzoate salt of emamectin were efficacious at controlling two economically important lepidopterous pests, *S. exigua* and *H. virescens,* in glasshouse tests. Excellent efficacy was found for up to 14-21 days after application under glasshouse conditions when emamectin benzoate was applied at the proposed field use rate (8.4 g ai/ha). A dry powder blend (80) was shown to be the most efficacious formulation tested.

Similar results were found in the field. A dry powder blend formulation (80) was shown to be very efficacious at controlling *H. zea, K. lycopersicella,* and *S. exigua* on tomato. Control was comparable to that achieved with the EC formulation, and comparable or superior to lambda cyhalothrin, permethrin, and methomyl. Satisfactory efficacy was also achieved with another dry powder blend (formulation 81), albeit it was slightly less effective than formulation 80 and the EC, especially when applied at 14-day intervals. The lower efficacy of formulation 81 compared with formulation 80 and the EC concurs with data from the residual efficacy tests conducted in the glasshouse. These data also agree with the solubility data for this formulation. This formulation had the lowest percentage of available emamectin benzoate (Table 1), which undoubtedly affected its efficacy at controlling lepidopteran pests.

Excellent efficacy of several formulations was found for up to 14 days when use rates were as low as 0.084 and 0.84 g ai/ha under glasshouse and simulated field conditions (i.e., plants sprayed indoors and moved between the glasshouse and outdoors daily), respectively. Such results with this compound are not uncommon in glasshouse environments, especially during the months of March and April in Ohio, when ultraviolet radiation (UV) is low. However, similar results would not be expected in the field because avermectins (e.g., abamectin) are very susceptible to photodegradation (MacConnell et al. 1989). They showed that the half-life of abamectin was < 10 h in light. Numerous photodegradates have subsequently been identified for both abamectin (Crouch et al. 1991) and emamectin benzoate (Feely et al. 1992). For these reasons, field use rates of between 8.4 and 16.8 g ai/ha are recommended for the compound (Anonymous 1995).

Slower photodegradation undoubtedly occurred in the present study in the glasshouse than what would be expected in the field during the growing season. Glasshouses are known to filter out a large percentage of UV light. Thus, when plants were indoors, emamectin benzoate residues were exposed to minimal levels of UV radiation. It is likely that the reduced photodegradation of emamectin benzoate in the glasshouse optimized the amount that was able to penetrate leaf tissue via translaminar movement and subsequently prolong the residual efficacy observed. MacConnell et al. (1989) showed that there were marked differences in the half-life of abamectin on Petri dishes and on leaves in light and dark environments and prolonged stability in the dark resulted in greater penetrability into leaves and improved efficacy at controlling mites.

Emamectin benzoate is being developed as a broad spectrum lepidoptericide on a wide variety of horticultural crops. Emamectin benzoate has an unprecedented potency against Lepidoptera (Dybas 1988, Dybas & Babu 1988, Mrozik et al. 1989), and has one of the lowest recommended use rates (8.4 g ai/ha) of all insecticides sold commercially or in development (another avermectin, abamectin, currently has the lowest recommended use rate, 5.4 g ai/ha) (Jansson & Dybas 1996). Emamectin benzoate is very compatible with IPM. It is extremely selective at killing a broad spectrum of lepidopterous pests at very low use rates, while conserving natural enemies (D. Cox et al., unpublished). Although the liquid EC formulation (0.16 EC) is considered a safe product, the development of a solid formulation of emamectin benzoate should further enhance its safety features. Solid formulations can reduce the need for plastic packaging thereby reducing the environmental burden. In addition, the use of solid formulations may eliminate the use of volatile organic solvents as part of a formulation's composition. Lastly, solid formulations can reduce overall exposure of workers to pesticides, especially when products are loaded into spray equipment.

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