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LABORATORY EVALUATION OF INSECTICIDES FOR CONTROL OF THE INVASIVE CACTOBLASTIS CATCTORUM (LEPIDOPTERA: PYRALIDAE)

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ABSTRACT

We conducted laboratory assays of nine products registered for use on ornamental plants in Florida for their ovicidal and larvicidal activity against the invasive cactus moth Cactoblastis catctorum. One-hundred percent mortality (or 0% survival) of 1-day-old eggs was obtained when eggstick sections were treated with cypermethrin, spinosad, or imidacloprid. These products were equally as effective when assayed against eggs that were fully embryonated (28 days old), when cladodes of Opuntia stricta were exposed to neonates 24 hours after dipping, or to cladodes that were dipped and stored for 30 days before exposure. When Bacillus thuringiensis (Dipel®) was used to prevent neonate penetration into treated cladodes of O. stricta, 100% mortality (or 0% survival) was recorded in the laboratory.

Key Words: insecticides, invasives, Cactoblastis catctorum, Lepidoptera, Pyralidae, cypermethrin, emamectin benzoate, abamectin, spinosad, azadirachtin, fenoxycarb, imidacloprid, acephate, Bacillus thuringiensis

RESUMEN

Nosotros realizamos unos ensayos del laboratorio de nueve productos registrados para el uso sobre plantas ornamentales en Florida para su actividad ovicida y larvacida contra la polilla invasora de cactus Cactoblastis catctorum. Una mortalidad de cien por ciento (o 0% sobrevivencia) de huevos de 1 día de edad fue obtenida en secciones de grupos de huevos tratados con cypermethrin, spinosad, o imidacloprid. Estos productos fueron igualmente efectivos en ensayos contra huevos con embriones completamente desarrollados (de 28 días de edad), cuando los cladodios de nopal de Opuntia stricta fueron expuestas a neonatas (larvas recientemente nacidas) 24 horas después ser emergidos, o a los cladodios que fueron emergidos en insecticida y almacenados por 30 días antes de ser expuestos. Cuando Bacillus thuringiensis (Dipel®) fue usado para prevenir la penetración de las neonatas dentro los cladodios de O. stricta tratados, un mortalidad de 100% (o 0% sobrevivencia) fue registrada en el laboratorio.

Cactoblastis catctorum (Berg) successfully controlled several species of invasive prickly pear cacti (Cactaceae: Opuntioideae—Opuntia) in Australia (Dodd 1940), South Africa (Petley 1948), and in many other parts of the world (Moran & Zimmermann 1984). In 1989 C. catctorum was detected in the Florida Keys (Habeck & Bennett 1990; Dickel 1991). The cactus moth may have arrived through natural dispersal from the Caribbean Islands, where it was intentionally introduced in the 1950s (Simmonds & Bennett 1990), or it may have been accidentally introduced by the nursery trade (Pemberton 1995). Nevertheless, its rapid spread along the Atlantic and Gulf Coasts has raised concerns about its unavoidable impact on native Opuntia cacti in the southern United States and in Mexico (Zimmermann et al. 2000). Stiling (2002) suggested that the geographical range of C. catctorum in Florida was expanding at an approximate rate of 50-75 km per year. However, unpublished data collected by our group suggests that the spread rate along coastal locations in the Gulf of Mexico was closer to 160 km per year during 2000-2003 (S. D. Hight, unpublished data). Given this rapid rate of geographical expansion, C. catctorum could arrive in Texas by the year 2007. Invasion and establishment of the cactus moth in the southwestern United States and in Mexico will have serious detrimental effects on biodiversity and stability of native desert ecosystems and on vegetable, fruit, and forage Opuntia industries in these areas.
(Soberón et al. 2001; Zimmermann et al. 2000). Even though *C. cactorum* was deliberately introduced into South Africa to control invasive cacti, spineless *Opuntia* is still used as fodder for cattle and other livestock during times of drought. As such, livestock farmers manage their *Opuntia* plantations in order to minimize losses due to insect damage.

The biology of *C. cactorum* is well documented (Dodd 1940; Pettey 1948; Zimmermann et al. 2000). Mating occurs one hour before sunrise (Hight et al. 2003) and eggs are laid to form spine-like eggsticks, each with 60-100 eggs. Neonates burrow collectively into cactus cladodes (pads or stems) where larvae feed gregariously and move to new pads as old ones are destroyed. Pupation occurs in plant litter or soil. The moth completes three full generations in Florida, with peak adult flights taking place in April, July, and October (Zimmermann et al. 2004).

Burger (1972) was the first to report on the use of cover sprays of methidathion and carbaryl to protect *Opuntia* plantations in South Africa against attack by both *C. cactorum* and *Dactylopius opuntiae* (Cockerell) (Homoptera: Dactylopiidae). Subsequently, Pretorius et al. (1986) and Pretorius & Van Ark (1992) assayed additional products applied either as cover sprays or stem injections to prevent cladode penetration by first instar *C. cactorum*. Pretorius et al. (1986) indicated that cover sprays of cypermethrin gave excellent results. However, they found that stem injections of monocrotophos gave inadequate control and were expensive and impractical to use against the insect. Pretorius & Van Ark (1992) evaluated additional products (mevinphos and dimethoate) as both stem injections and cover sprays and discovered that these materials applied as sprays translocated effectively through the plants and provided good protection against larval attack. According to Nel et al. (2002), the insecticides currently registered for use against *C. cactorum* in South Africa include a carbamate (carbaryl), an organophosphate (methidathlon), and two pyrethroid insecticides (deltamethrin and tralomethrin).

The current infestation of *C. cactorum* in Florida is affecting native *Opuntia* species distributed throughout large expanses of natural areas (*O. stricta* (Haworth) Haworth, *O. humifusa* (Raf.) Raffinesque, and *O. pusilla* (Haworth) Nutall), as well as ornamental cactus plants (*O. ficus-indica* (L.) Miller and *O. stricta*) in urban settings (Hight et al. 2002). Even though chemical control is not a practical or environmentally responsible tactic to protect the millions of hectares of natural *Opuntia* vegetation (Mahr 2001), insecticide controls should be evaluated for their potential use in urban settings. Leibee & Osborne (2001) summarized information on new insecticides to be assayed for use against immature stages of the cactus moth. If proven effective, these products could be employed in culturally managed plantings of *Opuntia* (nurseries, backyards, landscaped public lands) either alone or in combination with other suppression tactics. Furthermore, insecticides could be used to treat ornamental *Opuntia* in nursery settings to ensure that no infested plants are being sold to the public. In this paper we report results of laboratory assays of several insecticides that are registered for use on ornamental plants in Florida. Ovicidal and larvicidal properties of the products were examined and results obtained are discussed in context of the area-wide management of this invasive insect.

**Materials and Methods**

**Test Insects**

Eggsticks used in these experiments came from a laboratory colony of *C. cactorum* maintained at the USDA-ARS Crop Protection and Management Research Unit, Tifton, Tift Co., GA. The insects are reared on cladodes of *O. stricta* inside rectangular plastic boxes (25 by 17 by 8 cm) that are held in environmental chambers at 26 ± 1°C, a 14:10 (L:D) photoperiod, and 70% RH during larval and pupal development. Cocoons are collected twice per week, de-silked in a dilute bleach solution, and pupae are sorted by gender. Groups of 30-50 newly emerged adults of each gender are placed together in aluminum screen cages (35 by 35 by 35 cm) containing 1-3 cladodes of *O. stricta* for mating and oviposition. Eggsticks are collected from the cages once per day, placed in small plastic cups (60 ml), and maintained at 26 ± 1°C, a 14:10 (L:D), and 70% RH until needed. Under these conditions eggsticks take approximately 30 d to complete their development.

**Products Assayed**

Studies were conducted during 2004 at the UF/IFAS North Florida Research and Education Center (NFREC), Quincy, Gadsden Co., FL. Nine different commercially available products were tested in the laboratory for their ovicidal and larvicidal activity against *C. cactorum*. The products were cypermethrin (Ammo® 2.5 E, FMC Corporation, Philadelphia, PA), emamectin benzoate (Proclaim® 5 SG, Syngenta Crop Protection Inc., Greensboro, NC), abamectin (Avid® 1.5 EC, Syngenta Crop Protection, Inc., Greensboro, NC), spinosad (SpinTor® 2 SC, DowAgro Sciences LLC, Indianapolis, IN), azadirachtin (Azatin® EC, AgriDyne Technologies Inc., Salt Lake City, UT), fenoxycarb (Distance® IGR, Valent U.S.A. Corporation, Walnut Creek, CA), imidacloprid (Admire® 2 F, Bayer Corporation Crop Protection, Kansas City, MO), and acephate (Orthene® 75 SP, Valent U.S.A. Corp., Walnut Creek, CA). In addition, the bacterial insecticide *Bacillus thur-
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ingiensis Berliner (Dipel®, Valent U.S.A. Corp., Walnut Creek, CA) was evaluated against neo-

nate larvae. Two dilution rates (1.0× and 0.5×) were chosen for each product by averaging the

high and low recommended application rates for each material. The average dilution rate was as-

signed 1.0× and the rate was halved for the 0.5× rate. Only the 1.0× rate was used for B. thuringi-

ensis. All products were mixed with de-ionized water and used within 30 minutes of preparation.

Ovicidal Tests

Cactus moth eggsticks were transported to

NFREC where they were divided into sections

that contained a minimum of 10 eggs and ran-

domly assigned to treatments. Egg mortality was

assessed on both newly laid (1-d-old) as well as on

fully embryonated (28-d-old) egg sticks. For each

product and dilution rate, eggstick sections were

dipped in the treatment solution for 5 s, allowed

to air-dry and placed individually inside plastic

Petri dishes. Dishes were stored in the laboratory

at ambient conditions (25 ± 2°C, 13:11 (L:D), and

about 30% RH). Five replicates were completed

each experiment and differences between means

were separated by the Waller-Duncan K-ratio

t-ttest (P ≤ 0.05). Likewise, all dependent variables

examined yielded similar results and all signifi-
cant differences in the multiple range tests were

the same. Consequently, only data on percent sur-

vival of C. cactorum in each of the four experi-

ments are presented.

RESULTS AND DISCUSSION

Leibee & Osborne (2001) suggested possible in-
secticides to screen against the cactus moth. These
insecticides are presently registered for use on or-
namental plants in Florida and labeled as effective
against Lepidoptera that bore into plant tissue
(Leibee & Osborne 2001). Six of the nine products
suggested by these authors were evaluated in our
experiments. The three additional products that
we tested were cypermethrin (a synthetic ester
pyrethroid) which is extremely effective against
larvae to penetrate the cladode. Results of each
experiment were assessed after d 15 by counting
the total number of eggs per eggstick and number
of eggs that hatched per replicate. Using this in-
formation, each cladode was destructively sam-
pred for both newly dipped cladodes and cla-
dodes that were dipped and stored for 30 d. Controls were dipped in de-ionized water and handled as above.

Statistical Analysis

Data from each experiment (ovicidal tests on
1-d-old or 28-d-old eggs and larvicidal tests for
newly dipped cladodes and for cladodes that were
dipped and stored for 30 d) were analyzed by two-

factor analysis of variance (ANOVA) with product
dilution rate as main effects. Interaction be-
 tween product and dilution rate was included in
the model (PROC ANOVA) (SAS Institute 1989).

Dependent variables included percent mortality

and percent survival, as well as the corrected
mean percent mortality with the Schneider-Orelli
formula for mortality data from a uniform popu-

lation (Zar 1984). In addition, arcsine trans-
formed data for each dependent variable were in-
cluded in the statistical model to satisfy the as-
sumptions of ANOVA. Because no significant ef-
fect due to product dilution was detected and
because no significant interactions were revealed
during the analysis, data for both dilution rates
(1.0× or 0.5×) for each product were pooled for
each experiment and differences between means
were separated by the Waller-Duncan K-ratio t-
test (P ≤ 0.05). Likewise, all dependent variables
examined yielded similar results and all signifi-
cant differences in the multiple range tests were
the same. Consequently, only data on percent sur-

vival of C. cactorum in each of the four experi-

ments are presented.
Juss), and the bacterial pesticide *B. thuringiensis* (tested only against neonates).

A summary of our laboratory results is shown in Table 1. Survival of immature stages of *C. cactorum* varied between 64 to 85% when eggsticks were treated with de-ionized water (control). However, one hundred percent mortality (or 0% survival) of 1-d-old eggs was obtained when eggstick sections were treated with cypermethrin, spinosad, or imidacloprid. These products were equally as effective (94 to 100% mortality) when assayed against eggs that were fully embryonated (28 d old), when cladodes of *O. stricta* were exposed to neonates 24 h after dipping, or to cladodes that were dipped and stored for 30 d before exposure. Cypermethrin has been reported to be highly toxic to bees and aquatic insects (US EPA 1989). Pretorius et al. (1986) reported that cypermethrin had good activity against immature *C. cactorum* in South Africa when applied as a cover spray to spineless *Opuntia*. The results of our laboratory assays agree with the data reported by these authors. Spinosad is a macrocyclic lactone insecticide reported to have wide margins of safety for many beneficial insects and related organisms (Schoonover & Larson 1995). Imidacloprid is a nicotinoid insecticide that has minimal environmental and safety concerns associated with its use (Leibee & Osborne 2001). However, it has been found to be acutely toxic to a variety of predatory insects (Mizell & Sconyers 1992).

Emamectin benzoate is an avermectin insecticide that exhibits low toxicity on beneficial insects (Leibee & Osborne 2001). This product was effective at killing eggs and larvae of *C. cactorum* in the laboratory, although some survival of neonates was detected in three of four laboratory assays (Table 1). The second avermectin insecticide that was assayed, abamectin, showed good activity against newly laid and fully embryonated eggs of *C. cactorum*, as well as against neonates that were challenged with newly dipped cladodes. However, the product was ineffective after the cladodes were stored for 30 d. When *B. thuringiensis* was used to prevent neonate penetration into treated cladodes of *O. stricta*, 100% mortality (or 0% survival) was recorded in the laboratory. When we evaluated the results of the assays with *B. thuringiensis*, we found replicates where larvae had been successful at creating an entry hole into the cladode; however, no larvae survived to cause damage beyond this small opening. Finally, azadirachtin, fenoxycarb (a juvenile hormone mimic) and acephate (an organophosphate) were moderately to totally ineffective against immature stages of the cactus moth (Table 1). Lowered effectiveness of some products, such as insect growth regulators (IGRs), may partially be due to feeding behavior of neonate larvae. Eggs hatch synchronously and larvae enter the cladode as a group through a single to few holes. Consequently, few individuals feed on the surface of the cladodes and ingest IGRs sprayed on the surface.

Habeck & Bennett (1990) suggested that widespread use of pesticides was not recommended as a method of control for cactus moth in the Florida Keys because of the occurrence of rare and endangered lepidoptera such as the Schaus swallowtail *Papilio aristodemus ponceanus* Schaus, Florida leaf-wing *Anaea floridalis* Johnson & Comstock and Bartram’s scrub-hairstreak *Strymon acis* (Drury). We believe that similar concerns exist for

### Table 1. Effect of Different Insecticides on Percent Survival of *Cactoblastis cactorum* Treated as Eggs That Were Newly Laid (1-D-Old) or Ready to Hatch (28-D-Old) and Larvicidal Activity of the Products When Newly Emerged Neonates Were Exposed to Cladodes of *Opuntia stricta* that Had Been Dipped After 24 H or Dipped and Stored for 30 D.

| Product               | Ovicidal Tests | Larvicidal Tests |
|-----------------------|----------------|------------------|
|                       | Eggs 1-d-old   | Eggs 28-d-old    | 24 h post cladode treatment | 30-d post cladode treatment |
| Control (H₂O)         | 80 ± 20.8 a    | 85 ± 11.0 a      | 64 ± 44.4 a                  | 81 ± 9.4 a                  |
| Cypermethrin          | 0 c            | 0 c              | 0 c                          | 0 c                         |
| Emamectin Benzoate    | 5.8 ± 7.4 c    | 0.6 ± 1.9 c      | 0 c                          | 7.9 ± 25.0 c                |
| Abamectin             | 4.3 ± 9.1 c    | 3.3 ± 8.4 c      | 0 c                          | 85.6 ± 8.5 a                |
| Spinosad              | 0 c            | 0 c              | 0 c                          | 0 c                         |
| Azadirachtin          | 52.7 ± 35.1 b  | 85.5 ± 11.5 a    | 54.6 ± 30.2 ab               | 43.6 ± 40.5 b               |
| Fenoxycarb            | 8.6 ± 27.1 c   | 40.3 ± 35.4 b    | 64.0 ± 35.2 a                | 73.9 ± 13.4 a               |
| Imidacloprid          | 0 c            | 0.6 ± 1.9 c      | 0 c                          | 3.6 ± 10.2 c                |
| Acephate              | 38.9 ± 33.4 b  | 39.7 ± 37.0 b    | 35.4 ± 38.7 b                | 87.3 ± 10.2 a               |
| *B. thuringiensis*    | —              | —                | 0 c                          | 0 c                         |

1. Means within each column followed by the same letter are not significantly different, Waller-Duncan K-ratio t-test (*P* ≤ 0.05).
all natural areas in Florida and elsewhere in the United States where Opuntia are currently infested, or are at risk of being infested, with C. cactorum. In these settings, the application of the Sterile Insect Technique (Carpenter et al. 2001; Hight et al. 2004) appears to be the only reasonable management tactic. However, the use of insecticides, together with the removal and destruction of eggsticks, infested cladodes, or entire plants, to protect Opuntia in nursery and backyard situations and as a tool to reduce cactus moth pest pressure in urban situations is still recommended. Furthermore, the protection of Opuntia plantations destined for fruit or vegetable production in Mexico cannot be overlooked as the insect steadily expands its geographical range to the West.

Our laboratory results suggest possible products that should undergo further evaluations in the field, in particular, B. thuringiensis, spinosad, and imidacloprid. However, we would anticipate a much more rapid breakdown in the effectiveness of B. thuringiensis in the environment due to increased exposure to UV light and rain events. Because these products are already registered for use on vegetables and ornamental plants in Florida, expanding their registration in other states is highly recommended and could perhaps lead to the eventual acceptance of these products for use in fruit and vegetable plantations of Opuntia in Mexico. Lastly, when formulations become available, field tests are recommended for isolates of AcMNPV, a nuclear polyhedrosis virus isolated from Autographa californica (Speyer) (Lepidoptera: Noctuidae). This isolate has been shown by Vail et al. (1984) to be moderately effective against immature stages of C. cactorum in the laboratory.

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