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# ORGANIC TREATMENTS FOR CONTROL OF PEPPER WEEVIL (COLEOPTERA: CURCULIONIDAE)

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## ABSTRACT

The pepper weevil, *Anthonomus eugenii* Cano (Coleoptera: Curculionidae) is a major pest of pepper (*Capsicum* spp.; Solanales: Solanaceae) in the southern United States, Mexico, Central America and the Caribbean. Feeding and oviposition cause flower and fruit abscission and internal fruit damage resulting in serious yield losses. Females lay eggs in flower buds and small fruits, shielding larvae from contact pesticides, leaving only the adult stage vulnerable. The purpose of this study was to investigate low-risk and organic products for use against the pepper weevil to provide both organic and conventional growers with more control options. A neem product (Ecozin® 1.2% ME), kaolin clay (Surround® WP), diatomaceous earth (Red Lake Earth®) and a product based on plant terpenes (Requiem®), were tested in lab and field trials for efficacy against pepper weevil. The neem product did not reduce feeding or oviposition in lab choice and no choice tests, so it was not tested in the field. Kaolin clay, diatomaceous earth and Requiem reduced feeding and oviposition in lab trials. Spring and fall field tests of these products were conducted in small plots along with a standard pesticide rotation of Actara and Vydate and an untreated control. The only treatment to increase marketable yield was the standard pesticide rotation. In the spring field trial, the standard treatment doubled yield per plant compared to the untreated controls but the yield was not different from those in the kaolin clay and surround plots. While the organic products did not increase marketable yield significantly, they did decrease overall damage, indicating possible usefulness in combination with conventional insecticides or in low population pressure by spraying early and following appropriate cultural practices such as adequate fallow periods and crop destruction. We recommend further testing of diatomaceous earth in particular in combination with conventional and organic insecticides as part of future IPM program research.

Key Words: *Anthonomus eugenii*, diatomaceous earth, kaolin, neem, Requiem, thiamethoxam, deterrent

## RESUMEN

El picudo (gorgojo) del chile dulce, *Anthonomus eugenii* Cano (Coleoptera: Curculionidae) es una plaga importante de chile dulce (*Capsicum* spp.; Solanales: Solanaceae) en el sur de los Estados Unidos, México, América Central y el Caribe. La alimentación y oviposición causa la abscisión de flores y frutos y el daño interno a los frutos que resulta en serias pérdidas de rendimiento. Las hembras ponen los huevos en los brotes de flores y frutos pequeños, protegiendo las larvas de los pesticidas de contacto, dejando sólo la etapa adulta vulnerable. El propósito de este estudio fue investigar el uso de los productos de bajo riesgo y orgánicos contra el picudo del chile para proveer tanto a los productores orgánicos y convencionales, más opciones de control. Un producto de neem (Ecozin®1.2% ME), arcilla de caolín (Surround ® WP), tierra de diatomeas (Red Lake Tierra ®) y un producto a base de terpenos vegetales (Requiem ®), fueron probados en el laboratorio y ensayos de campo para la eficacia contra el picudo del chile dulce. El producto de neem no redujo la alimentación o la oviposición en las pruebas de elección y no-elección en el laboratorio, por lo que no se puso a prueba en el campo. La arcilla de caolín, tierra de diatomeas, y Requiem redujeron la alimentación y oviposición en los ensayos de laboratorio. Se realizaron pruebas de campo en la primavera y el otoño de estos productos en pequeñas parcelas juntas con una rotación estándar de los pesticidas Actara y Vydate y un control no tratado. El único tratamiento que incrementó el rendimiento comercializable fue la rotación estándar de pesticidas. En el ensayo de campo de primavera, el tratamiento estándar se duplicó el rendimiento por planta en comparación con el tratamiento no tratado (el control), pero el rendimiento no fue diferente al de las parcelas

de arcilla de caolín y de las parcelas en el alrededor. Mientras que los productos orgánicos no incrementaron significativamente el rendimiento comercializable, su uso disminuyó el daño total, lo que indica su posible utilidad en combinación con insecticidas convencionales o de baja presión de la población por medio de aplicaciones de aspersión tempranas y después de las prácticas culturales apropiadas, tales como un período de barbecho adecuado y destrucción de cultivos. Se recomienda que se realicen más pruebas de substrato de diatomeas, en particular en combinación con insecticidas convencionales y orgánicos como parte de la investigación futura del programa de MIP.

Palabras Clave: *Anthonomus eugenii*, tierra de diatomeas, caolín, neem, Requiem, tiametoxam, efecto disuasivo

The pepper weevil, *Anthonomus eugenii* Cano (Coleoptera: Curculionidae) feeds preferentially on flower buds and oviposit preferentially on small fruits of pepper plants (*Capsicum* spp.), but most damage is caused by larval feeding which causes abscission and internal fruit damage. Eggs are laid singly inside a feeding cavity which is subsequently covered by an anal secretion forming a plug which contains an oviposition deterring pheromone that can reduce subsequent oviposition in the same fruit by the same female or conspecifics (Addesso et al. 2007). The weevils complete their development through the pupal and teneral adult stages inside the fruit which protects all but the mature adult stage from pesticide exposure. In addition to its protected habitat, rapid developmental time and high reproductive rate contribute to the weevil's pest status (Elmore et al. 1934; Toapanta et al. 2005).

The life cycle of the pepper weevil makes it a difficult pest to control with conventional pesticides and economic thresholds are extremely low. Adult weevils often hide within the whorls of newly expanding foliage near forming flower buds and other crevices, making them difficult to survey. Segarra-Carmona & Pantoja (1988) estimated that economic damage commences with adult populations of 0.01 beetle per plant or 1% infestation. Action thresholds of one adult per 400 terminal buds (0.25% infestation), monitored in the morning, have also been suggested (Riley et al. 1992a, 1992b). Migrations of pepper weevil into fields can also be monitored with aggregation pheromone traps available from Trécé, Inc., Adair, Oklahoma. Pesticide applications are recommended when the first weevil is detected in the pheromone traps (Mellinger & Bottenberg 2000). Adult pepper weevils migrate to solanaceous weeds surrounding pepper fields or remain in field debris between cropping seasons and reinfest the crop the following season (Mellinger & Bottenberg 2000). For these reasons, it is recommended that growers destroy nightshade weeds along the borders of their fields and disk under old pepper plants following harvest. Additional cultural control methods include avoiding successive plantings, shortened crop cycles, fallows and removal of fallen fruit from fields before beetles emerge (Webb et al. 2013).

Pesticide applications are necessary to control pepper weevil where populations are known to occur. Applications should begin when beetles are first detected and chemistries should be rotated to prevent resistance development. A grower standard often used for comparison in field testing in Florida includes 3 applications of Actara (active ingredient thiamethoxin, group 4A: neonicotinoid: nicotinic acetylcholine receptor agonists) (Syngenta Crop Protection, Inc., Greensboro, NC) followed by weekly applications of Vydate L (DuPont, Wilmington, DE) applications (active ingredient Oxamyl, group 1A: carbamate: acetylcholine esterase inhibitor (Stansly & Kostyk 2010). Maximum allowable seasonal application rates and long pre-harvest intervals are major limitations of this and other pesticide regimes.

The potential of biological control agents to augment conventional pepper weevil management programs has been investigated. Two species of parasitoid wasps were evaluated for use against pepper weevil: *Triaspis eugenii* Wharton and Lopez-Martinez (Hymenoptera: Braconidae) and *Catolaccus hunteri* Crawford (Hymenoptera: Pteromalidae). *Triaspis eugenii*, which attacks the pepper weevil during the egg stage, was successfully reared in the laboratory (Rodríguez-Levya 2006), but field populations in Florida failed to establish. The native larval ectoparasitoid, *C. hunteri*, is the most abundant species attacking the pepper weevil in Florida; however, the girth of most pepper fruit impedes access to the preferred 3rd instar host feeding deep inside on the nutritious seeds and placenta. Thus effectiveness of *C. hunteri* is limited to flower buds and the smallest fruit. Nevertheless, augmentative releases of the parasitoid during fallows, in nearby nightshade stands or early in the crops cycle when weevils are laying eggs in flower buds and newly developing fruit have been shown to reduce or delay damage (Schuster 2007).

Organic production of peppers in pepper weevil infested areas and the incorporation of biological control agents into cropping systems are both limited by the need to control adult weevils.

Reduced risk insecticides for use in pepper weevil management programs may allow for better use of biological control agents. Heavy crop losses from the pepper weevil may have discouraged investigation of organic pesticides, but some barrier and repellent products have been shown to be effective against other weevils and may prove useful in integrated management strategies for this pest. Neem extract products have shown some deterrent effect against boll weevil, *Anthonomus grandis grandis* Boheman (Coleoptera: Curculionidae) (Showler et al. 2004). Kaolin clay based products have been used to control plum curculio, *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae), in orchards (Wright et al. 2000). Diatomaceous earth is an effective mechanical pesticide against the rice weevil *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) and other grain beetles (Athanassiou et al. 2006). Powders and essential oil extracts of Mexican tea (*Dysphania ambrosioides* (L.) Mosyakin & Clemants, formerly *Chenopodium ambrosioides*) were effective toxicants against several grain weevil species (Tapondjou et al. 2002). The objective of this study was to evaluate the effectiveness of several organic products in suppressing pepper weevil oviposition. Commercial products containing neem oil (repellent, endocrine disruptor), kaolin clay (barrier/irritant), diatomaceous earth (barrier/irritant, mechanical pesticide) and Mexican tea extract (repellent, contact insecticide) were selected. Oviposition and fruit feeding damage was evaluated in choice and no-choice fruit bioassays, whole plant bioassays, and in small field plot trials.

## MATERIALS AND METHODS

### Insects and Plants for Bioassays

Pepper weevils used in the laboratory experiments came from a colony maintained at the University of Florida's Entomology and Nematology Department. The colony was periodically supplemented with field caught weevils from the Southwest Florida Research and Extension Center in Immokalee, Florida to maintain genetic diversity. Females used in these assays were at least 6 days old and were taken from individual colony rearing cups in which oviposition had been verified. Jalapeno pepper plants and fruit used in laboratory and greenhouse studies were grown in the greenhouse or outdoors at the University of Florida or USDA-ARS Center for Medical, Agricultural and Veterinary Entomology, Gainesville, Florida. Plants grown in 10-cm square pots in a 50:50 mixture of Metromix 200 and 500 potting soil (Sun Gro Horticulture Canada Ltd, Bellevue, Washington) were fertilized every other week with Peters Professional Water Soluble Fertilizer 20:20:20 (The Scotts Company, Marysville, Ohio).

Fruit measuring 4-5 cm in length were harvested in the morning prior to bioassay. Fruiting stage plants used in the whole plant choice assays were approximately 10 weeks old and were matched so they had the same number of fruit per plant.

### Fruit Bioassays

Fruit were treated with test compounds or water controls and presented to individual gravid females in choice and no-choice bioassays (15 replications of each treatment in each type of assay; Figure 1). Choice test compared a single untreated fruit to a fruit dipped in the appropriate insecticide suspension. Bioassays were run in square arenas ($10 \times 10 \times 10$ cm) with vented lids at approximately 27 °C and 40% RH. Numbers of eggs laid and feeding punctures produced (hole in a fruit but no egg) were recorded after 12 h. Ecozin® Plus 1.2% ME (containing 1.2% azadirachtin, hereafter referred to as Ecozin, AMVAC, Los Angeles, California) at rates equivalent to low (0.12% dip solution, 15 oz/acre) and high field rates (0.24% dip solution, 30 oz/acre), Requiem® (1% dip solution, containing synthetically manufactured terpene constituents of *Chenopodium ambrosioides* near *ambrosioides*, Bayer CropScience LP, Research Triangle Park, North Carolina), kaolin clay (5% dip solution, Surround® WP, Tessenderlo Kerley, Inc., Phoenix, Arizona) and diatomaceous earth (0.6% dip solution, Red Lake Earth, diatomaceous earth and calcium bentonite, food chemical codex grade, Kamloops, British Columbia, Canada) were tested.

### Whole Plant Bioassays

In these bioassays, Requiem, kaolin clay and diatomaceous earth on one treated plant was tested against an untreated control in chiffon-screened cages ($60 \times 60 \times 60$ cm) (Bioquip Products, Rancho Dominguez, California). Treatments were applied by a hand sprayer until runoff. Replications were conducted in a plexiglass house in Gainesville, Florida. Two females were introduced into each cage and the number of eggs laid and feeding punctures by females were recorded after 48 h. Twenty-two to 24 replicates were conducted for each treatment. Data are presented as eggs or feeding punctures per fruit to adjust for uneven numbers of fruit on control or treated plants.

### Field Trials

Spring 2010 Trial. Greenhouse-grown jalapeno pepper plants var. 'Tormenta' were transplanted at Southwest Florida Research and Extension Center (SWFREC) in Immokalee, Florida on Mar 1st 2010 at 45 cm spacing in single rows 73 m in length on 1.8 m centers. Rows were covered

with black polyethylene film mulch. Each 73 m bed was divided into 8 plots and treatments distributed in a randomized complete block design with 4 replicates. Each plot contained 10 pepper plants with 4 collard plants between plots to act as a buffer. Approximately 25% of the fertilizer was preplant soil incorporated (granular 13-2-13) with the remainder was applied as liquid 8-0-8 delivered with a Dosetron daily through drip irrigation. Foliar applications of treatments (Table 1) were made with a high clearance sprayer operating at 180 psi at 2.3 mph with spray delivered through 2 vertical booms fitted with 4 yellow Albuz® hollow cone nozzles that discharged 10 gpa each. Dropped fruit was confined to the bed top by 5 cm × 5 cm × 2.4 m wooden lathe fastened to the edges of the raised beds with ground cloth staples to prevent fruit from falling to the ground. On June 7, 14, 21, and 28th all fallen fruit (culls) were collected, counted and removed from the plots. All fruit greater than 5 cm in length was also removed from the plant and taken to the lab for evaluation. Externally damaged and undamaged fruit were separated, counted and weighed. Half of the undamaged fruit were cut longitudinally and inspected for pepper weevil larvae, with the percentage damaged used to estimate number of weevil-damaged fruit in each plot harvest. Thus, total number of culled fruit for each plot was equal to the number of fallen fruit, plus those harvested that were externally damaged. The percent of harvest that was infested was equal to the number of harvested fruit found to be infested upon inspection divided by the total number of inspected fruit multiplied by 100. The average number of larvae in infested harvested fruit was counted in the dissections. Marketable yield was estimated by taking the total number of fruit harvested and subtracting the number damaged. Harvests from each plot were pooled across all 4 weeks. Treatments were analyzed by averaging the 4 plots.

Fall 2010 Trial. Greenhouse-grown pepper plants were transplanted at the SWFREC in Immokalee, Florida on 15 Sep at 60 cm spacing in 4 single rows 91.4 m in length on 1.8 m centers and covered with white polyethylene film mulch. Each 91.4 m bed was divided into 9 plots and treatments distributed in a randomized complete block design with 4 replicates. Each plot contained 12 pepper plants with a 3.7 m space between plots for a buffer. For the first 2 weeks of harvest, no infestation was visible. Changes to protocol were made to account for the low infestation rate so that 50 fruit, randomly selected from the harvest, were inspected for pepper weevil damage instead of inspecting 50% of the harvested fruit as was done in Spring 2010 (up to 25 fruit). Dropped fruit were again confined to the bed top with wooden lathing, counted and examined. Total number of culled fruit, percent of harvest infested, number

TABLE 1. TREATMENTS AND APPLICATION COSTS IN SPRING AND FALL FIELD TRIALS OF ORGANIC INSECTICIDES AGAINST THE PEPPER WEEVIL.

| Treatments | Active Ingredient | Rates | Approximate Cost/Acre/Week | Spring Application Dates | Fall Application Dates |
|---|---|---|---|---|---|
| Untreated Control | | | | | |
| Standard Pesticides: Actara® first 3 weeks followed by Vydate® weekly | Actara: Thiamethoxam Vydate: Oxamyl | Actara: 3.67 oz/acre Vydate: 3 pts/acre | $9.00 $27.00 | Weekly 24 May – 25 Jun | Weekly 26 Oct – 24 Nov |
| Requiem® | | 4 qt/acre | $45.00 | | |
| Surround® WP | Kaolin clay | 50 lb/acre | $90.00 | | |
| Red Lake Earth | Diatomaceous earth | 5 lb/acre | $2.50 | | |

of larvae in infested harvested fruit and marketable yield were calculated as before but were analyzed on a per plant basis due to loss of some plants to disease.

Statistical Analysis

In the choice bioassays, egg counts, feeding puncture counts and total damage (combined egg and feeding puncture counts) were analyzed using the Wilcoxon Signed-Rank Test. The no-choice fruit bioassay data were analyzed with a Kruskal-Wallis Test. Whole plant data were analyzed by Wilcoxon Signed-Rank Test for paired non-parametric data. The fall and spring field trial data were analyzed separately due to a high pepper weevil and bacterial leaf spot infestations in the spring. Data for the entire growing season in each plot was pooled and analyzed on a per plant basis to account for differences in plot sizes. Culled fruit, number of larvae and marketable yield were analyzed using PROC GENMOD (SAS Version 9.3, SAS Institute, Inc., Cary, North Carolina, USA) assuming a Poisson distribution with a log = link function. If the chi-squared value for the model was significant, mean separation was performed using a Least Squares Means test with $\alpha$ = 0.05. Percent of harvest infested was converted to proportions, arcsine transformed and analyzed by PROC GLM.

## RESULTS

Fruit Bioassays

Choice Tests. No differences were observed in total damage (eggs laid or feeding punctures) between the control and either rate of Ecozin (Table 2). In contrast, the 3 remaining treatments, diatomaceous earth, kaolin clay, and Requiem, all resulted in significantly fewer eggs, feeding punctures, and total damage compared to the untreated control.

No Choice Tests. Punctured fruit and total damage were 3-fold greater in untreated fruit compared to fruit treated with either diatomaceous earth, kaolin clay, or Requiem ($\chi^2_{(3)}$ = 13.92, $P = 0.0030$ and $\chi^2_{(3)}$ = 12.61, P = 0.0056 respectively, Table 3). However, treatment effects on number of eggs laid was not significant ($\chi^2_{(3)}$ = 2.17, $P$ = 0.5381) although a similar trend was observed.

Whole Plant Bioassays

No significant decrease was observed in the number of eggs per fruit on plants treated with diatomaceous earth ($S = 2.5$, $P = 0.9375$; control = 1.7 ± 0.5 eggs/fruit, DE = 1.4 ± 0.3 eggs/fruit), kaolin clay ($S = 10$, $P = 0. 0.7684$; control = 1.4 ± 0.3 eggs/fruit, kaolin clay = 1.4 ± 0.3 eggs/fruit) or Requiem treatments ($S = 47.5$, $P = 0.0994$; control = 1.7 ± 0.9 eggs/fruit, Requiem = 0.9 ± 0.2 eggs/fruit).

Field Trials

Spring 2010 Trial. Infection of bacterial spot was extremely high in the spring of 2010, brought about by unseasonable rainfall. Pepper weevil infestations were also high, as is common in the spring due gradual buildup of populations over the previous season. The standard pesticide treatment was significantly different from the control in all categories: culled fruit, percentage fruit infested, larvae in harvested fruit, and marketable yield (Table 4). In contrast, there was no significant response of any kind to Requiem or diatomaceous earth. However, fruit from plants treated with Surround had fewer culled fruit, lower percentage of infested fruit, and fewer larvae than untreated fruit. While the number of marketable fruit was not significantly different from the control for this treatment, neither was it different from the standard treatment.

Fall 2010 Trial. Conditions were quite different in the fall with much less weevil pressure. Nevertheless, all treatments resulted in fewer culled fruit and lower percentages infested compared to the control with no differences among treatments (Table 4). However, number of larvae

TABLE 2. OVIPOSITION AND FEEDING BY FEMALE PEPPER WEEVILS IN CHOICE TESTS WITH UNTREATED JALAPENO FRUIT AND FRUIT TREATED WITH ORGANIC-APPROVED INSECTICIDES.

| Product | Total Eggs | | Total Feeding Punctures | | Total Damage | |
|---|---|---|---|---|---|---|
| | Treated | Control | Treated | Control | Treated | Control |
| Ecozin (15 oz/acre) | 22 | 25 | 2 | 11 | 24 | 36 |
| Ecozin (30 oz/acre) | 25 | 26 | 5 | 11 | 30 | 37 |
| Requiem | 7 | 40* | 14 | 44* | 21 | 84* |
| Kaolin clay | 11 | 33* | 4 | 14* | 15 | 47* |
| Diatomaceous earth | 6 | 49* | 8 | 31* | 14 | 80* |

*Control values followed by an asterisk are significantly greater than the corresponding treatment ($P < 0.05$ Wilcoxon Signed-Rank Test).

TABLE 3. Oviposition and feeding by female pepper weevils in no-choice tests on jalapeno fruit treated with organic-approved insecticides.

| Product | Total Eggs | Feeding Punctures | Total Damage |
|---------|-----------|-------------------|--------------|
| Control | 52 | 102 a | 154 a |
| Requiem | 37 | 32 b | 69 b |
| Kaolin Clay | 41 | 23 b | 64 b |
| Diatomaceous Earth | 44 | 22 b | 66 b |

*Values in the same column followed by a different lowercase letter are significant ($P < 0.05$ Kruskal-Wallis).

in fruit was only less than the control from plants treated with the standard, and there were no differences among treatments in marketable yield.

## DISCUSSION

Controlling pepper weevil infestations in Florida and other southern states is challenging, even with rotational programs of conventional pesticides as evidenced by the results of our own field trials. Under heavy pressure in the spring, nearly 66% of fruit treated with the conventional products were lost to pepper weevil. Those losses dropped to 34% under low pressure conditions in the fall. These levels of yield loss are typical in production systems where pepper weevil pressure is high. Biological control agents, such as *C. hunteri*, are not sufficient to control populations in the field and are not compatible with conventional pesticides. The organic products evaluated in this study for efficacy against pepper weevil were chosen because of their lower toxicity and potential for incorporation into rotational and integrated management plans for both conventional and organic systems.

Azadirachtin has been shown to act as a feeding and oviposition deterrent, growth regulator and reproductive inhibitor of numerous species of insects (Mordue & Blackwell 1993). Showler et al. (2004) demonstrated that Ecozin 1.2% ME (a formulation containing 1.2% azadirachtin as the active ingredient) reduced both the number of feeding punctures and eggs laid by the boll weevil, *Anthonomus grandis grandis* Boheman, for up to 24 h in laboratory choice assays. However, the same deterrent response was not observed from the pepper weevil in 24 h no-choice tests. In our study, Ecozin had no effect on oviposition by the pepper weevil in laboratory assays at either the 0.12% or the 0.24% concentrations corresponding to the 179.5 mL/ha (15 oz/ac) or 359 mL/ha (30 oz/ac) rates. While a small decrease in the number of excess feeding punctures was observed, the difference was not great enough for statistical significance. Furthermore, the large numbers of eggs laid made the reduced feeding damage inconsequential. Since no decrease in oviposition was observed at the low or high rates of Ecozin in the laboratory, the product was dropped out of

further evaluation in our study. It is important to note, however, that other formulations of neem products which contain combinations of neem oil extracts, azadirachtin and synergists may result in better efficacy. It is also significant to note that Showler et al. (2004) saw better efficacy of the neem products tested when they were aged outdoors under UV, which was not done in this study. While outdoor aging resulted in a significant reduction in feeding punctures and eggs by the boll weevil at 24 h, by 48 h the product was no more effective than untreated controls, suggesting a re-application interval of 3 days, which would be impractical for most growers.

The active ingredients in Requiem are a combination of biologically active terpenes based on the extract of the Mexican tea plant (*Dysphania ambrosioides* [L.] Mosyakin & Clemants; Caryophyllales: Amaranthaceae), formerly *Chenopodium ambrosioides* L.). Mexican tea extract has previously been demonstrated as an effective anthelminthic (MacDonald et al. 2004), antifungal (Kumar et al. 2007), pesticide (Cloyd & Chiasson 2007; Chu et al. 2011; Nenaah & Ibrahim 2011) and repellent (Gillij et al. 2008). Extracts of D. *ambrosioides* were successfully tested as a fumigant for stored products pests including the maize weevil (Chu et al. 2011). While the fumigant effects of D. *ambrosioides* products may be useful for stored product pests, its use as a pesticide against weevils with other life histories was not previously tested.

Requiem showed much better efficacy in laboratory choice tests as it suppressed both oviposition and feeding damage. It also suppressed feeding in no-choice tests. In the whole plant choice assays, Requiem cut oviposition by nearly half over a 48 h period but the variation was such that the values were not significant. Interestingly, in both the Spring and Fall field plot trials, there was no significant difference in marketable yield between Requiem treated plants, untreated controls or the standard pesticide regime. Despite improving 2 measures of infestation during the low pest pressure Fall treatments, including number of culled fruit and percent of harvest infested, these factors did not result in a significant improvement in marketable yield. Thus reduction of pepper weevil feeding and oviposition by Requim

Table 4. INFESTATION VALUES AND NUMBER OF MARKETABLE FRUIT PER PLANT IN SPRING AND FALL FIELD TRIAL PLOTS OF JALAPENO PEPPER PLANTS TREATED WITH ORGANIC-APPROVED INSECTICIDES, A STANDARD PESTICIDE ROTATION AND UNTREATED CONTROLS ON A PER PLANT BASIS.

| | Treatments (Mean ± SEM) | | | | |
| | Requiem | Diatomaceous Earth | Surround WP | Standard Pesticide | Untreated Control |
|---|---|---|---|---|---|
| **Spring 2010** | | | | | |
| Culled Fruit | 32.6 ± 11.2 a | 27.7 ± 7.7 ab | 14.8 ± 1.3 b | 15.2 ± 3.3 b | 36.7 ± 3.1 a |
| % of Harvest Infested | 30.7 ± 5.3 a | 15.0 ± .9 bc | 10.8 ± 1.9 c | 8.7 ± 2.1 c | 23.2 ± 2.2 ab |
| Larvae in Harvested Fruit | 3.3 ± 0.8 ab | 2.3 ± 0.9 abc | 1.7 ± 0.3 bc | 1.3 ± 0.5 c | 3.7 ± 0.6 a |
| Marketable Yield | 5.3 ± 1.0 c | 10.0 ± 2.4 abc | 10.9 ± 2.5 ab | 12.4 ± 2.7 a | 6.7 ± 0.4 bc |
| **Fall 2010** | | | | | |
| Culled Fruit | 12.6 ± 3.1 b | 9.4 ± 4.7 b | 9.9 ± 3.3 b | 5.3 ± 1.4 b | 31.9 ± 9.4 a |
| % of Harvest Infested | 1.8 ± 0.6 b | 2.4 ± 1.0 b | 1.5 ± 0.6 b | 0.9 ± 0.7 b | 11.8 ± 3.8 a |
| Larvae in Harvested Fruit | 0.8 ± 0.2 ab | 0.7 ± 0.2 ab | 0.5 ± 0.2 ab | 0.2 ± 0.2 b | 1.2 ± 0.2 a |
| Marketable Yield | 11.3 ± 1.1 | 12.8 ± 1.1 | 11.5 ± 1.0 | 11.9 ± 1.2 | 8.8 ± 1.2 |

*Mean in rows followed by the same letter are not significantly different ($P < 0.05$ by Least Square Means).ww

in laboratory assays did not translate to strong or consistent activity under field conditions. Possibly, rapid loss of volatile terpene compounds in the Requiem formulation to the environment may limit the effectiveness of the product in the field.

Diatomaceous earth is a naturally occurring, soft, sedimentary rock formed from the fossilized remains of diatoms. The product used in this study was a commercially available diatomaceous earth containing 67% silicon dioxide. The product is considered a physical insecticide, causing damage to the cuticle resulting in desiccation or as a feeding deterrent (Athanassiou et al. 2006, 2011). This product reduced feeding damage and oviposition in choice tests, but only feeding in nochoice assays. In field trials, application of diatomaceous earth to pepper plants did not improve any measured criteria under high weevil pressure in the spring but did reduce damage and percentage infestation along with all other treatments in the fall.

The insecticidal activity of different diatomaceous earth products depends on the geological and geographical sources, silica content, pH, tapped density and adherent ability (Korunic 1998). Athanassiou et al. (2011) found that the effectiveness of diatomaceous earth from several southern Europe sources against 3 species of grain beetle depended on the source of the product, the insect species tested, the temperature and relative humidity at which the bioassay was conducted. We selected this product because of its availability and approved food grade rating by the Organic Materials Review Institute (OMRI), www.omri.org. It is possible that other sources of diatomaceous earth may be more effective against pepper weevil. In addition, the generally high humidity in south Florida pepper fields may explain the decrease in effectiveness of diatomaceous earth compared to laboratory assays.

Kaolin clay is a hydrophilic particle film used as a visual repellent and feeding and oviposition deterrent for insects. Hydrophilic kaolin clay particle film was effective at suppressing 2 other weevil pests, plum curculio (Lalancette et al. 2005) and boll weevil (Showler 2002). Kaolin clay reduced pepper weevil oviposition in laboratory choice tests but counts were too low to be significant for feeding damage. In the no choice assay, a reduction in the number of feeding punctures was observed but not in eggs laid. It reduced 3 damage criteria under high weevil pressure in the fall. Although marketable yield was not significantly more than the untreated control in the fall, neither was it significantly less than the standard rotation which did improve yields significantly. Thus, while not a clear winner, it did perform a cut above the other organic products in the field.

None of the products tested, aside from the Standard Pesticide rotation in the spring improved marketable yield over the untreated con-

trol, despite some reduction of infestation. Cost is always a consideration and Requiem and Surround provided no clear yield effect at 2 to 10 times high cost per acre (Table 1). Diatomaceous earth may warrant further testing as a combination treatment to improve the efficacy of contact pesticides. Through a combination of deterrence and injury to the weevil cuticle, it may have the potential to both decrease feeding and oviposition damage and provide a better opportunity for contact pesticides to act. At an additional cost of $2.50/wk, such a combination may be acceptable for growers of organic and conventional peppers if its addition is found to improve yields.

Conventional insecticides are vital for managing pepper weevil, but as this study has shown, even a weekly control plan with pesticide rotation cannot completely control pepper weevil. Cultural controls that limit initial emigration into the crop are necessary to maintain populations at a manageable level during the crop cycle. The addition of barrier products such as diatomaceous earth to an integrated management program have the potential to increase production in conventional systems and organic production systems.

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