Responses of Chilli Thrips (Thysanoptera: Thripidae) to Capsicum Cultivars in Choice Tests in the Greenhouse and Laboratory and Relative Benefits of Protecting these Cultivars with Spinetoram

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RESPONSES OF CHILLI THRIPS (THYSANOPTERA: THRIPIDAE) TO *CAPSICUM* CULTIVARS IN CHOICE TESTS IN THE GREENHOUSE AND LABORATORY AND RELATIVE BENEFITS OF PROTECTING THESE CULTIVARS WITH SPINETORAM

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Abstract

Since the chilli thrips, *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae) poses a considerable threat to production of peppers in the Western Hemisphere, it is important to determine the relative vulnerability of different cultivars of *Capsicum annuum* L. and *C. chinense* Jacquin. In addition it is important to determine the relative benefits to the productivity of these cultivars of controlling the chilli thrips with insecticides. Therefore the effects of the chilli thrips on 11 pepper cultivars (*Capsicum* spp.; Solanales: Solanaceae) were tested in greenhouse and laboratory environments. When data for spinetoram-treated and untreated plants of each cultivar were pooled, the number of pedicels, number of flowers, and total (pedicels + flowers + fruit) differed between cultivars, and 'Astry' and 'Cheyenne' had the highest counts of these organs, while 'Hot Habanero Orange' and 'Hot Fatalli' had the least. When cultivars were pooled for spinetoram-treated separately from untreated plants, spinetoram was found to have increased the numbers of pedicels and total counted plant organs. For spinetoram-treated plants, 'Hot San Ardo' had the greatest canopy volume and 'Hot Fatalli' the smallest, whereas 'Fresno 6022' had the most fruits and 'Hot Fatalli' had the least. Based on comparing canopy volume and number of fruits of spinetoram-treated and untreated plants, 'Numex Big Jim' was found to have been benefitted the least by spinetoram application, whereas 'Fresno 6022', 'Hot Tormenta', 'Cheyenne', 'Astry', and 'Jamaican Yellow' were benefitted the most. A greenhouse choice test indicated 'Fresno 6022', 'Hot Tormenta', 'Hot Fatalli', 'Hot San Ardo', 'Hot Habanero Orange', 'Numex Big Jim', and 'Jamaican Yellow' each had fewer larvae per plant than 'Astry'. In a choice of cultivars in laboratory Petri dishes, larvae per leaf disk were most abundant on 'Agriset 4108', 'Red Devil Cayenne', 'Numex Big Jim', 'Astry', and 'Jamaican Yellow' and least abundant on 'Hot Fatalli'. 'Hot Fatalli' attracted the fewest thrips and seemed to be the least susceptible cultivar in the 3 experiments, though it had the smallest plant size and lowest yields. Spinetoram improved yields of productive cultivars like 'Fresno 6022', which may be more feasible to grow than 'Hot Fatalli'.

Key Words: *Scirtothrips dorsalis, Capsicum annuum, Capsicum chinense,* spinetoram

Resumen

Porque los trips de pimienta, *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae) esta amenazanda la producción de pimientas en el Hemispherio Occidental, es importante determinar las vulnerabilidades relativos de cultivares diferentes de *Capsicum annuum* L. y *C. chinense* Jacquin. Tambien es importante determinar los beneficios relativos a las productividades de estos cultivares quando los trips de pimienta estan contolada para las insecticidas. Por lo tanto, se evaluaron los efectos de trips de pimienta en 11 cultivares de pimienta *(Capsicum* spp.; Solanales: Solanaceae) en el Centro Tropical de Recherche y Educación del Universitario de Florida, Homestead, en invernaderos y el laboratorio. Quando plantas tratados y no tratados fueron combinados para cada cultivar, fuéron differencias entre cultivares por los tallos de flores cortados, flores, y totales (tallos cortados + flores + frutas) y 'Astry' y 'Cheyenne' fueron mas altas y 'Hot Habanero Orange' y 'Hot Fatalli' mas bajas. Quando cultivares fueron combinados para las plantas tratados y por los no tratados, spinetoram aumentó las quantidades de tallos de flores cortados, y totales de órganos contados de las plantas. 'Hot San Ardo' fué mas alta y 'Hot Fatalli' mas baja por volumen del follaje tratado, y 'Fresno 6022' fué mas alta y 'Hot Fatalli' mas baja por frutas tratadas. Basado en la comparación del volumen de follaje y numero de frutas para plantas tratadas y no tratadas, 'Numex Big Jim' fué menos ayudado y 'Fresno 6022', 'Hot Tormenta', 'Cheyenne', 'Astry', y 'Jamaican Yellow' mas ayudados para aplicación de spinetoram. Una prueba de preferencia en invernadero indicó que 'Fresno 6022', 'Hot Tormenta', 'Hot Fatalli', 'Hot San Ardo', 'Hot Habanero Orange', 'Numex Big Jim', y 'Jamaican Yellow' tuvieron menos larvas por cada planta que 'Astry'. Una prueba de preferencia para las cultivares de pimienta en placas Petri en una cámara de crecimiento del laboratorio muestro que 'Agriset 4108', 'Red Devil Cayenne', 'Numex Big Jim', 'Astry', y 'Jamaican Yellow' obtuvieron las mas larvas por disco de hoja y 'Hot Fatalli' obtuvo los menos. 'Hot Fatalli' atrajo los menos trips de todo las cultivares y pareció a ser la menos susceptible en todo los tres experimentos, aunque tuvo las tamaños de plantas y rendimientos mas pequeños. Spinetoram mejoró los rendimientos de cultivares productivos como 'Fresno 6022', lo qual puede ser mas practico a criar que 'Hot Fatalli'.

Palabras Claves: *Scirtothrips dorsalis, Capsicum annuum, Capsicum chinense,* spinetoram

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Two types of peppers (*Capsicum* spp.; Solanales: Solanaceae) are produced commercially in the USA: bell peppers (mild) and chile peppers (spicy) (ERS 2008). In 2007, USA pepper production entailed about 22,000 ha of bell peppers and 10,000 ha of chile peppers with farm gate market values of $468 million and $120 million, respectively (ERS 2008). Chilli thrips, *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae), is native to southern Asia (Dev 1964; Kumar 2012), and has become a serious pest of ornamental, fruit, and vegetable crops in Asia, Oceania, Africa, the Caribbean, North America including Florida, and other tropical and subtropical regions (Ananthakrishnan 1993; CABI/EPPO 1997; CABI 2003; Seal et al. 2006). The polyphagy of *S. dorsalis* renders it problematic on many crops, which inspires research into various control methods including host-plant resistance.

Insecticides such as imidacloprid (Provado®, Bayer Crop Sciences, Research Triangle Park, North Carolina), spinosad (Spintor®, Dow AgroSciences, Indianapolis, Indianapolis), and spinetoram (Radiant®, Dow AgroSciences, Indianapolis, Indianapolis) are among the most effective for reducing densities of larvae and adult *S. dorsalis* (Seal et al. 2006). Spinetoram is a spinosyn in Insecticide Resistance Action Committee (IRAC) Mode-of-Action Class #5, or nicotinic acetylcholine receptor allosteric activator (IRAC 2012). However, insecticide use has disadvantages, such as the expense and toxicity to humans, wildlife, biocontrol agents, and the development of insecticide resistance. *Cryptolaemus* sp. (Coleoptera: Coccinellidae) exemplifies predatory biocontrol agents that may be harmed by these pesticides (Seal et al. 2006). As an alternative to pesticide use, significant resistance to thrips has been found in commercial accessions for at least 5 cultivated plant species including tomato *Lycopersicon esculentum* Mill. (Solanales: Solanaceae) (Kumar et al. 1995) and peppers (Fery & Schalk 1991; Maris et al. 2003c, 2004).

Herbivorous insects use a variety of general and host-specific cues to find their plant foods (Schoonhoven et al. 1998; Addesso & McAuslane 2009). Once an herbivorous insect finds a host, short-range olfactory, mechanical, and gustatory cues verify the suitability of the plant for feeding or oviposition. Other cues such as species-specific pheromones may further influence the mate and host-plant selection process (Addesso & McAuslane 2009). Beck (1965) defined plant resistance as "the collective heritable characteristics by which a plant species, race, clone, or individual may reduce the probability of successful utilization of that plant as a host by an insect species, race, biotype, or individual." There are 2 types of resistance, antibiosis and non-preference, and these differ from tolerance (Beck 1965). In antibiosis, a plant is resistant by exerting an adverse influence on the growth and survival of an insect, while in non-preference, a plant displays resistance by exerting an adverse effect on the insect's behavior (Beck 1965). Horber (1980) defined tolerance as "all plant responses resulting in the ability to withstand infestation and to support insect populations that would severely damage susceptible plants." In one study, tolerance mechanisms, not antibiosis or antixenosis (non-preference), imparted reduced vulnerability to *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae) by some *C. annuum* L. germplasm lines (Kogan & Ortman 1978; Horber 1980; Fery & Schalk 1991). Da Costa et al. (2011) found significant differences in preference by *Aphis gossypii* Glover (Hemiptera: Aphididae) for different cultivars of *Capsicum* spp., and the semiochemical mixture released by the least-preferred cultivar was more repelling than that of the most preferred cultivar. Similarly, Maris et al. (2004) found a decreased adult preference, residence time, oviposition, and increased larval mortality of *F. occidentalis* on thrips-resistant *C. annuum* 'CPRO-1' compared to thrips-susceptible *C. annuum* 'Pikante reuzen'. These factors reduced the direct damage from thrips and the indirect damage from *Tomato spotted wilt virus* (TSWV) vectored by the thrips (Maris et al. 2003 a, b, c, 2004).

The main hypothesis tested in this study was that some *Capsicum* cultivars were significantly more susceptible to *S. dorsalis* than others. A secondary hypothesis tested was that use of spinetoram to control *S. dorsalis* on *Capsicum* cultivars with various susceptibilities may have different degrees of practical value. We conducted

3 tests of our hypotheses: 1 test with insecticide-treated and non-treated infested plants of 11 *Capsicum* cultivars in a greenhouse to examine plant damage and numbers of *S. dorsalis*, and 2 choice tests of *S. dorsalis* between the 11 *Capsicum* cultivars, i.e., one in a greenhouse and one in laboratory Petri dishes.

Materials and Methods

Studies were conducted to determine responses of *S. dorsalis* populations to the application of spinetoram and the resulting plant damage on 11 *Capsicum* cultivars. For this, 3 tests were performed at the Tropical Research and Educational Center (TREC), Homestead, Florida, during the summer of 2011 to early winter of 2012 in 2 greenhouses and a laboratory growth chamber (Percival I36LL incubator, Percival Scientific, Perry, Iowa). The experiments included a test of spinetoram treatment and pepper cultivars in an open greenhouse (Site A), a choice test in a more closed greenhouse (Site B), and 2 other choice tests in a laboratory growth chamber (Site C).

Capsicum Cultivars Utilized

'Agriset 4108' is a F_1 hybrid, 'Jalapeño'-derived cultivar from the USA with 9.7 × 3.3-cm, dark green to red fruit that require 70 days from planting to harvest (Reimer Seeds 2012). 'Fresno 6022' is another F_1 hybrid with more visibly pubescent leaves than the other pepper cultivars; it produces 7.6 × 3.3-cm, cone-shaped, green to bright red peppers, which require 74 days from planting to harvest (Reimer Seeds 2012). 'Hot Tormenta', another F_1 hybrid from the USA, produces 10.2 × 3.8-cm, dark green to red peppers; it has very good disease resistance and needs 77 days from planting to harvest when green (Reimer Seeds 2012). 'Hot San Ardo', another F_1 hybrid, produces 15.2 × 7.6-cm, green to red peppers requiring 75 days from planting to harvest with very good disease resistance (Reimer Seeds 2012). 'Cheyenne', a F_1 hybrid derived from 'Cayenne', has 20-23-cm-long fruits, and requires 65 days (green) to 85 days (red) from planting to maturity or bloom (Johnny Seeds 2012). 'Hot Habanero Orange' is from the USA and has orange, 2.5 × 3.8-cm fruits that require 90 days from planting to harvest (Generic Seeds 2012). 'Red Devil Cayenne' is a F1 hybrid derived from 'Cayenne' that produces 12.7 × 0.8-cm, green-to-red fruits that require 72 days from planting to harvest (Reimer Seeds 2012). 'Numex Big Jim' was developed by New Mexico State University, USA, and produces green-to-red, 30.5 × 7.1-cm peppers that require 85 days from planting to harvest (Chile Pepper Institute 2012, Reimer Seeds 2012). 'Astry', a F1 Hungarian pepper type, has 12.7 × 9.7-cm, cream to bright red peppers, which require 70 days from planting to harvest (Reimer Seeds 2012). *Capsicum chinense* Jacquin (Solanaceae) cultivars include 'Hot Fatalli' from the Central African Republic, which produces 6.4 × 2.5-cm, green-to-yellow peppers, which take 95 days from planting to harvest (Reimer Seeds 2012) and 'Jamaican Yellow' (Jamaican Scotch Bonnet, Yellow Strain 1) from Jamaica, with 3.8 × 3.8-cm, green to yellow fruit that require 100 days from planting to harvest (Reimer Seeds 2012). None of these 11 cultivars has been issued a certificate for legal protection in the USA (PVPO 2012). All 9 cultivars of *C. annuum* and 2 of *C. chinense* have green stems, green leaves, white flowers, are upright, and 40 to 90 cm tall when mature.

Responses of *S. dorsalis* to Spinetoram-Treated and Untreated *Capsicum* Cultivars in an Open Greenhouse (Site A).

The greenhouse was 10.4 × 18.3 m and exposed to full sun with a roof of translucent fiberglass panels resulting in 60% light blockage. The entrances, juncture to the head house, and about half the areas of the east and west walls were open, hence, it was a more open greenhouse than at Site B. The test was conducted on plastic greenhouse benches, each 2.4 m × 0.91 m × 60 cm high, held 1 replication, and with potted plants placed on inverted, 128-plant styrofoam starter trays (34 × 67 × 6 cm).

Mean temperatures at 60 cm above ground level were 24.7 °C (range 15-34 °C) for Oct 2011, 22.6 °C (range 10-31 °C) for Nov, 21.1 °C (range 9-29 °C) for Dec, and 18.4 °C (range 1-30 °C) for Jan 2012 (FAWN 2012). RH at 2 m averaged 83, 79, 78, and 75% for Oct, Nov, Dec, and Jan, respectively (FAWN 2012). To determine these data, measurements were made from 10 AM to 4 PM EST, then added to values from the Homestead FAWN station. The foregoing values were 0.6 ± 1.9 °C (n = 31) above the mean temperature and 2.6 ± 12.3% (n = 31) below the mean RH of the FAWN station at TREC in Homestead (FAWN 2012).

Between 14 Jul and 9 Sep 2011, 1-2 seeds of each cultivar were planted per cell of a 128-plant styrofoam starter tray with one cultivar per tray, 2 to 6 trays per cultivar, and 11 cultivars total. On 18-19 Oct, 60 plants of each cultivar were repotted from planter trays into 10-cm pots, except for 'Cheyenne', which had 57 plants. Thus there were 4 or 5 plants per treatment per cultivar. The single-plant pots and styrofoam trays used the same potting soil: a standard potting mix (Fafard Growing Mix 2, Conrad Fafard Co., Agawam, Massachusetts), which consisted of Canadian sphagnum peat moss (70%), perlite (25%), and vermiculite (5%). Each plant was manually watered once per day with 16.2 ± 7.5 mL of tap water. On 20 Oct, 8 and 28 Nov, and 6 Dec 2011, plants were fertilized with 20-20-20 liquid fertilizer (Peters water soluble fertilizer, Scotts Co., Marysville, OH) according to manufacturer instructions with a fertilizer dispenser attached to a sprayer. To encourage uniform vegetative growth while allowing a later assessment of early flowering and fruiting, flowers and fruit were pruned from all plants before 1 Dec 2011 except for their pedicels, which remained on plants to be counted later. Unwanted insect infestations included greenhouse whiteflies *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae) mainly on pepper plants and green peach aphids *Myzus persicae* (Sulzer) (Hemiptera: Aphididae) mainly on cotton plants. On 17 Nov 2011, plants were sprayed with a mixture of pyriproxyfen (Knack®, Valent Co., Walnut Creek, California) at 8 oz/ac (568 g/ha) for whiteflies and beta-cyfluthrin (Baythroid® XL, Bayer CropScience, Research Triangle Park, North Carolina) at 3.45 oz/ac (245 g/ha) for aphids. Follow-up applications were made on 7 and 23 Dec, but only with pyriproxyfen (Knack®). On all 3 dates, a 4-gal (15-L) backpack sprayer (Birchmeier Iris, Birchmeier Co., Switzerland) delivered 100 gal/ac (948 liter/ha) of pesticide solution.

Four or 5 treated plants per cultivar formed the control groups by removal of *S. dorsalis* by spinetoram treatment. Five experimental plants per cultivar remained untreated and infested with thrips by natural migration from 130 thrips-infested cotton plants (*Gossypium hirsutum* L., Malvales: Malvaceae) placed on greenhouse benches and possibly from populations outside the greenhouse. Each thrips-infested cotton plant was 23-41 cm tall in a 10-cm-wide pot that was placed on benches 0.35-16.5 m from the pepper plants. Each group of plants per cultivar was sprayed or not sprayed with spinetoram and was randomly placed among the other 21 treatment combinations within each replication (bench). To facilitate removal of treated plants for spraying, each styrofoam tray held all treated or all untreated plants. Treated and untreated trays were randomized within each replication, as were the cultivars; hence, a randomized complete block design was used. On 3, 6, 24, and 28 Nov 2011, trays of insecticide-treated plants were moved to parallel benches under the same experimental conditions as untreated plants but were separated by 92-112 cm from benches of untreated plants. This distance helped to ensure that treated plants could be sprayed without the spray drift accidentally reaching untreated plants. Spinetoram insecticide was applied with a 1-L hand-pump sprayer at 8 oz /ac (584 mL /ha) of soluble concentrate delivering 70 gal/ac (655 L/ha) total volume applied to plants followed by their return to their original places on the experimental benches.

In an initial survey (25-26 Oct 2011), the proportions of plants infested and *S. dorsalis* population abundances were surveyed by carefully observing 2 leaves per treatment per replication using a hand-held magnifying glass (16 X). Data were also collected on plant width, depth, height, number of fruit, number of previously cut pedicels, and flowers and flower buds per plant (at least 1 mm diam). Plant height and width were measured 1-15 Dec 2011 and pedicels of early flowers or fruit, numbers of flowers, and fruit were measured 19 Dec 2011-3 Jan 2012 with all treatments in a replication measured on the same date for each variable. Pedicels of flowers and fruit removed before 1 Dec were distinguished as suberized, cut-off stumps beginning 19 Dec when counted along with the newer flowers and fruit; hence, total plant organs counted = (pedicels + flowers + fruit). Plant canopy volume was estimated by calculating the volume of the "cylinder" formed by the mean radius of the minimum and maximum branch spreads and the plant height by modifying the formula for cylinder volume: $(\pi\ r^2)*h = \{\pi \times [0.25 \times (\text{smallest diam of branch spread} + \text{largest diam of branch spread})]^2 \times (\text{plant height})\}$.

In the initial survey of infested and control plants (Site A), proportions infested, numbers of larvae, adults, and sum of larvae and adults were compared by one-way ANOVAs followed by Waller-Duncan multiple range tests for mean separation. For numbers of flowers, fruit, cut pedicels, total counted organs, and estimated plant volume, there were 2 pesticide treatments: treated (non-infested) and non-treated (infested) and 11 cultivars, thus, a 2-treatment × 11-cultivar factorial design. Each insecticide-cultivar treatment combination had 6 replications and 5 plants, except for replications 4-6 of treated 'Cheyenne', which had 4 plants. A 2-way factorial analysis of variance (ANOVA) was used to determine if there were significant interactions between pesticide and cultivar treatments. For estimated canopy volume and fruit counts, cultivar and treatment data were not pooled, but for pedicels, flowers, and total counted organs, cultivar data were pooled to compare pesticide treatments and pesticide treatments were pooled to compare cultivars. Effects of pesticide and cultivar on plant canopy volume, cut pedicels, flowers, fruit, and total counted organs were compared using non-paired T-tests between pesticide treatments or one-way ANOVAs followed by Waller-Duncan multiple range tests for mean separation among cultivars.

Choice Test with Small *Capsicum* Plants in a Closed Greenhouse (Site B).

A 4.1 × 9.4-m glass-panel greenhouse was used with an A-shaped roof (2.0 m to 2.6 m tall) covered by shade cloth and exposed to full sun resulting in

70% light blockage. For ventilation, the north door of the greenhouse was left open, and vents along the top of the roof formed 2 parallel openings 7.6 cm × 9.4 m separated by 1.2 m. The same kind of plastic greenhouse benches with the same kind of inverted styrofoam starter trays were used as in Site A, but each tray held one replication.

Mean temperatures 60 cm above ground level were 30.3 °C (range 21-39 °C) for Oct 2011, 28.2 °C (range 16-37 °C) for Nov, 26.7 °C (range 15-34 °C) for Dec, and 24.0 °C (range 7-35 °C) for Jan 2012. RH at 2 m averaged 93, 89, 88, and 85% for Oct, Nov, Dec, and Jan, respectively (FAWN 2012). To determine these data, measurements were made from 10 AM to 5 PM EST, then added to values from the FAWN station in Homestead resulting in greenhouse temperatures 6.2 ± 3.0 °C (n = 36) above the mean temperature and 7.2 ± 17.3% (n = 36) above the mean humidity of the FAWN station at TREC (FAWN 2012).

There were 10 cultivars (all except 'Cheyenne') and 6 replications: 3 replications with 2 leaves per plant and 3 replications with 4 leaves per plant. Plants with 4 leaves per plant probably would provide a larger amount of material to lure more *S. dorsalis* than 2 leaves per plant. However, plants with 2 leaves provided less material possibly allowing a given number of *S. dorsalis* to aggregate on a smaller number of leaves rendering them easier to find then with more leaves per plant.

Plants in Site B were obtained from the same starter trays, had the same potting soil, fertilizer regime, and control of unwanted pests as in Site A, and were manually watered once a day with 11.4 ± 2.9 mL tap water. On 27-31 Oct 2011, 10 plants of each cultivar were repotted from the starter trays into the final 10-cm-wide pots used in the experiment. For each replication (inverted starter tray), there were 10 potted pepper plants with one plant (5-23 cm tall) per cultivar. Each pepper plant was randomized within the circumference of an oval 30 × 40 cm between centers of pepper plants. Centers of pepper plant pots were 10 to 15 cm apart in the circumference of the oval, and each plant was spaced 10 to 40 cm from the other 9 pepper plants and 10 to 30 cm from the center of each cotton plant in the oval. The oval surrounded 5 cotton plants each 25 to 48-cm tall, growing in 10 to 11-cm-wide plastic pots, and infested with thrips. Also there were about 500 cotton plants in the greenhouse 10-38 cm tall, spaced 0.1 to 6 m from the pepper plants, and infested with *S. dorsalis*.

On 4 Nov 2011, an initial survey of numbers of *S. dorsalis* on all leaves of 6 cotton plants helped to determine infestation levels. On 7, 15, 21-22, and 29 Nov, numbers of *S. dorsalis* adults and larvae were recorded by carefully observing the topmost leaf of each pepper plant using a handheld magnifying glass (16 X). *Scirtothrips dorsalis* were sampled from the topmost leaf because of the preference by larvae and adults for newer growth (Dev 1964; Shibao et al. 1993; Seal et al. 2006, 2010). Numbers of adults, larvae, and total larvae and adults were analyzed by repeated measures ANOVAs. Measurements on dates with significant results were also analyzed individually by one-way ANOVA, but only the resulting Waller-Duncan mean separation tests, which are not available with repeated measures ANOVAs, were used in the results and tables.

Laboratory Choice Test with Leaf Disks from *Capsicum* Cultivars (Site C)

The growth chamber for the test was maintained at 25 ± 1 °C, 90 ± 1% humidity, 14:10 h L:D, and 29 $u$moles/m^2/s light intensity. There were 6 replications and ten cultivars in the first test with large larvae ('Cheyenne' was omitted) and 9 replications and 9 cultivars in the second test with small larvae ('Cheyenne' and 'Hot Habanero Orange' were omitted). Each replication involved a large plastic Petri dish (138 mm interior diam × 14 mm interior height) lined with a layer of cotton 3 ± 2 mm thick saturated with tap water. On top of the cotton layer was placed a 124-mm-diam disk of Parafilm M laboratory film (American National Can, Chicago, Illinois). About 5-10 mm of the underlying white cotton was folded over the top of the parafilm to overlap and thus prevent the larvae from escaping. The underlying cotton had extra reinforcement so it was not thinner than the rest of the cotton beneath the parafilm. Leaf disks 25 mm in diam were collected from plants in a greenhouse, refrigerated for 1-11 days at 6.1-7.2 °C, then placed on top of the parafilm. The cotton leaf disk was in the center surrounded by the disks of *Capsicum* cultivars spaced with edges 2-7 mm apart and randomized in a circle with closest edges 17-24 mm from the edge of the cotton leaf disk. Replications 1-9 began with large larvae (mostly second instar) while replications 10-18 used small larvae (mostly first instar). We used first and second instars to better represent the species than if only one instar was tested: data trends may occur with one instar that are not evident with the other instar. For each test, we released 33-34 larvae onto the central cotton leaf disk, then numbers of larvae per leaf disk were recorded at 24 h and 48 h after infestation. For the third measurement, however, data were not available for the test with large larvae at 72 h or with small larvae at 120 h. Thus, we used data for 120 h after infestation for the test with large larvae and 72 h after infestation for the test with small larvae. Larval counts per leaf disk were analyzed by one-way ANOVA followed by the Waller-Duncan multiple range test for mean separation to determine responses of *S. dorsalis* to different pepper cultivars.

Statistical analyses

Data for proportion infested (Site A) were transformed by arcsin [square root (n)] and all other data (Sites A-C) by [square root (n + 0.25)], but non-transformed data are shown in the results and tables. All statistical analyses were performed with SAS statistical software (SAS Institute 2012).

Results

Responses of *S. dorsalis* to Spinetoram-Treated and Untreated *Capsicum* Cultivars in an Open Greenhouse (Site A).

In the initial survey of *S. dorsalis* on 2 leaves per plant, significant differences were found between cultivars in proportion infested (Table 1) but not in numbers of larvae, adults, or total larvae and adults. 'Agriset 4108', 'Fresno 6022', 'Hot Habanero Orange', 'Red Devil Cayenne', 'Numex Big Jim', 'Astry', and 'Jamaican Yellow' each had significantly higher proportions infested than 'Hot Tormenta' or 'Hot Fatalli' (Table 1). There were significant interactions ($P \le 0.05$) between treatment and cultivar for numbers of fruit per plant (F = 4.14, df = 10, P = < 0.0001) and estimated canopy volume (F = 2.19, df = 10, P = 0.023), but not for cut pedicels (F = 1.80, df = 10, P = 0.068), numbers of flowers (F = 0.91, df = 10, P = 0.529), or total counted organs per plant (F = 1.20, df = 10, P = 0.302) (Tables 1 and 2). There were significant differences between cultivars for pedicels, flowers, and total counted organs (Table 1). 'Fresno 6022', 'Hot San Ardo', 'Cheyenne', and 'Astry' each produced significantly more flowers per plant than 'Agriset 4108', 'Hot Tormenta', 'Hot Habanero Orange', 'Numex Big Jim', 'Jamaican Yellow', or 'Hot Fatalli'. 'Agriset 4108', 'Hot Tormenta', and 'Cheyenne' were "early bloomers" with significantly more cut-off pedicels per plant than 'Hot San Ardo', 'Hot Habanero Orange', 'Numex Big Jim', or 'Hot Fatalli' with 'Agriset 4108' significantly higher than all other cultivars for pedicels. 'Astry', 'Fresno 6022', 'Hot San Ardo',

Table 1. Proportion of plants infested with *Scirtothrips dorsalis* and its damage effects on 11 pepper cultivars in the greenhouse (site A): initial survey and factorial data with no interactions.

	Initial survey	Pooled pesticide treatments (treated and untreated)		
	Proportion infested[1, 2, 3]	Number of cut pedicels/plant [2, 3]	Number of flowers/plant [2, 3]	Total (cut pedicels, flowers, fruit)/plant [2, 3]
Capsicum annuum	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
'Agriset 4108'	1.0 ± 0.0 a	0.55 ± 0.55 a	3.2 ± 1.6 cd	4.4 ± 2.5 bc
'Fresno 6022'	1.0 ± 0.0 ab	0.12 ± 0.28 bc	5.9 ± 3.0 a	7.0 ± 3.5 a
'Hot Tormenta'	0.7 ± 0.3 d	0.22 ± 0.34 b	3.5 ± 1.8 c	4.3 ± 2.4 bc
'Hot San Ardo'	0.9 ± 0.1 cd	0.02 ± 0.06 c	5.3 ± 2.0 ab	5.7 ± 2.3 ab
'Cheyenne'	0.9 ± 0.1 cd	0.20 ± 0.22 b	6.0 ± 2.0 a	7.1 ± 2.3 a
'Hot Habanero Orange'	1.0 ± 0.0 ab	0.00 ± 0.00 c	0.1 ± 0.3 e	0.2 ± 0.4 e
'Red Devil Cayenne'	1.0 ± 0.0 ab	0.07 ± 0.13 bc	4.0 ± 2.5 bc	4.7 ± 3.3 bc
'Numex Big Jim'	1.0 ± 0.0 a	0.02 ± 0.06 c	3.4 ± 2.5 cd	3.6 ± 2.7 cd
'Astry'	1.0 ± 0.0 ab	0.08 ± 0.10 bc	7.3 ± 4.0 a	7.9 ± 3.8 a
C. chinense				
'Hot Fatalli'	0.3 ± 0.1 e	0.00 ± 0.00 c	0.0 ± 0.0 e	0.0 ± 0.0 e
'Jamaican Yellow'	0.9 ± 0.2 bc	0.07 ± 0.10 bc	2.4 ± 3.0 d	2.7 ± 3.0 d
P [4]	< 0.0001 *** [6]	< 0.0001 *** [12]	< 0.0001 *** [12]	< 0.0001 *** [12]
Pooled cultivars Variable		**Untreated**	**Treated**	**P** [5]
Flowers [3]		3.5 ± 3.5	4.0 ± 2.8	0.2017 NS [66]
Cut pedicels [3]		0.05 ± 0.14	0.19 ± 0.34	0.0008 *** [66]
Total counted organs [3]		3.6 ± 3.5	5.1 ± 3.5	0.0148 * [66]

[1]Proportion of pepper plants infested with *S. dorsalis* 25 Oct 2011.
[2]Different letters indicate significant differences among cultivars based on significant ANOVA results followed by Waller-Duncan multiple range tests (P < 0.05) (SAS institute 2012).
[3]For statistical analyses, data for proportion infested were transformed by arcsin [square root (n)] and all other data by [square root (n + 0.25)], but non-transformed data are shown.
[4]Significance levels at * $P \le 0.05$, ** $P < 0.01$, *** $P < 0.001$, and NS (non-significant), were determined with a one-way ANOVA (SAS institute 2012); number of replications in each group compared is given in brackets.
[5]Significance levels at * $P \le 0.05$, ** $P < 0.01$, *** $P < 0.001$, NS (non-significant), and NA (not available) were determined with a non-paired t-test; number of replications in each group compared is given in brackets (SAS institute 2012).

and 'Cheyenne' produced significantly more total counted organs than 'Hot Habanero Orange', 'Numex Big Jim', 'Jamaican Yellow', or 'Hot Fatalli'; 'Astry' ranked highest in total counted organs and flowers. However, 'Hot Habanero Orange' and 'Hot Fatalli' had significantly fewer flowers and total counted organs than all other cultivars, and for pedicels, they were in the lowest statistical grouping and had the fewest (Table 1). When cultivars were pooled for spinetoram treatment, there were no significant differences between treated and untreated plants for flowers, but pedicels and total counted organs were each significantly higher for treated than untreated plants (Table 1).

Canopy volume was significantly higher for treated than untreated plants for 'Hot Fatalli', 'Hot San Ardo', 'Hot Habanero Orange', and 'Red Devil Cayenne' (Table 2), while numbers of fruit were significantly higher for treated than untreated plants for 'Agriset 4108'. Neither canopy volume nor fruit differed significantly between treated and untreated plants for 'Numex Big Jim', though both canopy volume and fruit were significantly higher for treated than untreated plants for 'Fresno 6022', 'Hot Tormenta', 'Cheyenne', 'Astry', and 'Jamaican Yellow'. Among the 11 cultivars, canopy volume differed significantly for treated and for untreated plants, and numbers of fruit differed significantly for treated but not for untreated plants (Table 2). For treated canopy volume, 'Hot San Ardo', 'Hot Tormenta', 'Cheyenne', 'Red Devil Cayenne', and 'Astry' were each significantly higher than 'Hot Fatalli', 'Agriset 4108', 'Hot Habanero Orange', 'Numex Big Jim', or 'Jamaican Yellow' with 'Hot San Ardo' highest and 'Hot Fatalli' lowest. 'Red Devil Cayenne', 'Agriset 4108', 'Hot Tormenta', 'Hot San Ardo', 'Cheyenne', and 'Astry' were each significantly higher than 'Hot Habanero Orange', 'Fresno 6022', 'Jamaican Yellow', or 'Hot Fatalli' in untreated canopy volume with 'Red Devil Cayenne' highest and 'Hot Habanero Orange' lowest. For treated fruit, 'Fresno 6022', 'Agriset 4108', 'Hot Tormenta', and 'Cheyenne' were each significantly higher than 'Hot Fatalli', 'Hot Habanero Orange', or 'Numex Big Jim' with 'Fresno 6022' highest and 'Hot Fatalli' lowest.

Greenhouse choice test with small plants (Site B). An initial survey of *S. dorsalis* (4 Nov 2011) on 6 randomly chosen plants found 479 ± 157 thrips per cotton plant indicating abundant thrips for inoculation. There were no significant differences between cultivars in numbers of adults or total larvae and adults for any measurement, or in numbers of larvae on the first, third, or fourth measurements. However for the second measurement (15 Nov), there were significant differences between cultivars in larvae per pepper plant (Table 3). 'Astry' had significantly more larvae than 'Hot Fatalli', 'Fresno 6022', 'Hot Tormenta', 'Hot San Ardo', 'Hot Habanero Orange', 'Numex Big Jim', or 'Jamaican Yellow' with 'Hot Fatalli' lowest.

Laboratory Choice Test with Leaf Disks from *Capsicum* Cultivars (Site C)

There were no significant differences between cultivars in numbers of larvae per leaf disk at 24 h after infestation for either instar or 48 h after infestation for first instars. However, for second instars at 48 h, 120 h, and first instars at 72 h, there were significant differences between cultivars (Table 4). At 48 h, 'Red Devil Cayenne', 'Agriset 4108', 'Fresno 6022', 'Hot San Ardo', Numex Big Jim', and 'Astry' each had significantly more larvae than 'Hot Fatalli' or 'Hot Habanero Orange' with 'Red Devil Cayenne' highest and 'Hot Fatalli' lowest. 'Jamaican Yellow' at 120 h had significantly more larvae than 'Hot Fatalli', 'Fresno 6022', and 'Hot Habanero Orange' with 'Jamaican Yellow' highest and 'Hot Fatalli' lowest. For first-instar larvae at 72 h, 'Agriset 4108' had significantly more than 'Hot Fatalli', 'Hot San Ardo', or 'Fresno 6022' with 'Agriset 4108' highest and 'Hot San Ardo' and 'Hot Fatalli' lowest.

Discussion

In the initial survey of *S. dorsalis* on 2 leaves per pepper plant (Site A), 'Agriset 4108', and 'Numex Big Jim' were in the highest statistical grouping for proportions of infested plants suggesting they were among the quickest to become infested. Here, 'Agriset 4108', and 'Numex Big Jim' and were each higher than 'Hot Tormenta' and 'Hot Fatalli', which were in the lowest statistical groupings, hence, the slowest to become infested. In the greenhouse choice test (Site B), there were differences between cultivars only in the second of 4 measurements and only for larvae per pepper plant. Many plants in the greenhouse choice test lost all their leaves becoming lost data points and contributing to high variability, which may have reduced the number of significant results occurring in the tests. For plants in greenhouses including the initial survey for *S. dorsalis* at Site A and the choice test with larvae at Site B, 'Hot Fatalli' attracted the fewest thrips and was in the lowest statistical grouping in each test. In the test of large larvae at 48 h and 120 h and small larvae at 72 h, 'Hot Fatalli' also attracted the fewest *S. dorsalis* and was in the lowest statistical grouping in all 3 measurements. 'Hot Fatalli' seemed to be the least susceptible cultivar because it tended to attract the fewest *S. dorsalis* across the 3 experiments. Also, 'Hot Fatalli' was in the lowest statistical groupings for canopy volumes, pedicels, flowers, fruit, and total counted

TABLE 2. EFFECTS OF *SCIRTOTHRIPS DORSALIS* ON 11 *CAPSICUM* SP. CULTIVARS EITHER TREATED WITH SPINETORAM OR NOT TREATED IN THE GREENHOUSE (SITE A): FACTORIAL DATA WITH INTERACTIONS. SPINETORAM INSECTICIDE WAS APPLIED WITH A 1-L HAND-PUMP SPRAYER AT 8 OZ /AC.

	Canopy volume[1, 2, 3]			Number of fruit[1, 2, 3]		
C. annuum	Untreated (cc)	Treated (cc)	P [4]	Untreated	Treated	P [4]
'Agriset 4108'	1578 ± 527 ab	2029 ± 281 de	0.0778 NS	0.07 ± 0.10 a	1.37 ± 1.11 abc	0.0161 *
'Fresno 6022'	893 ± 287 c	2363 ± 356 cd	<0.0001***	0.07 ± 0.10 a	2.00 ± 1.42 a	0.0087 **
'Hot Tormenta'	1649 ± 460 ab	3340 ± 1192 b	0.0050 **	0.00 ± 0.00 a	1.10 ± 0.65 abc	0.0045 **
'Hot San Ardo'	1863 ± 709 a	4257 ± 1552 a	0.0039 **	0.07 ± 0.16 a	0.70 ± 0.77 cde	0.0683 NS
'Cheyenne'	1645 ± 793 ab	3291 ± 702 b	0.0041 **	0.00 ± 0.00 a	1.76 ± 0.83 ab	0.0006 ***
'Hot Habanero Orange'	204 ± 83 d	919 ± 431 f	0.0002 ***	0.00 ± 0.00 a	0.10 ± 0.24 ef	0.3632 NS
'Red Devil Cayenne'	1957 ± 906 a	3208 ± 794 b	0.0285 *	0.27 ± 0.65 a	1.00 ± 1.05 bcd	0.1082 NS
'Numex Big Jim'	1196 ± 231 bc	1465 ± 206 e	0.0629 NS	0.00 ± 0.00 a	0.33 ± 0.55 def	0.1549 NS
'Astry'	1357 ± 357 ab	2791 ± 657 bc	0.0008 ***	0.20 ± 0.33 a	0.93 ±0.41 abcd	0.0068 **
C. chinense						
'Hot Fatalli'	302 ± 132 d	816 ± 294 f	0.0014 **	0.00 ± 0.00 a	0.00 ± 0.00 f.	NA
'Jamaican Yellow'	855 ± 315 c	1545 ± 224 e	0.0024 **	0.03 ± 0.08 a	0.50 ± 0.28 cdef	0.0007 ***
P [5]	< 0.0001 ***	< 0.0001 ***		0.5273	NS < 0.0001 ***	

[1]Data are means ± SD per plant.
[2]Different letters indicate significant differences among cultivars based on significant ANOVA results followed by Waller-Duncan multiple range tests ($P < 0.05$) (SAS institute 2012).
[3]For statistical analyses, all data were transformed by squareroot (n + 0.25) but only non-transformed data are shown.
[4]Significance levels at * $P \leq 0.05$, ** $P < 0.01$, *** $P < 0.001$, NS (non-significant), and NA (not available) were determined with a non-paired T-test (SAS institute 2012); number of replications in each group compared was 6.
[5]Significance levels at * $P \leq 0.05$, ** $P < 0.01$, *** $P < 0.001$, and NS (non-significant), were determined with a one-way ANOVA (SAS institute 2012); number of replications in each group compared was 6.

TABLE 3. NUMBERS OF *SCIRTOTHRIPS DORSALIS* IN THE GREENHOUSE CHOICE TEST WITH SMALL PLANTS OF 10 *CAPSICUM* SP. CULTIVARS AT SITE B. DATA OBTAINED IN THE SECOND MEASUREMENT[1] (15 NOV 2011).

Cultivar	Number of Adults[2,3] Mean ± SD	N[3]	Number of Larvae[2,3] Mean ± SD	N[3]	Total (larvae + adults)[2,3] Mean ± SD	N[4]
1. 'Agriset 4108'	7.5 ± 4.3 a	6	19.5 ± 14.3 ab	6	27.0 ± 13.0 a	6
2. 'Fresno 6022'	5.7 ± 4.3 a	6	12.3 ± 10.9 b	6	18.0 ± 13.2 a	6
3. 'Hot Tormenta',	8.8 ± 2.2 a	5	11.0 ± 11.0 b	5	19.8 ± 11.7 a	5
4. 'Hot Fatalli'	11.0 ± 10.7 a	5	9.6 ± 1.5 b	5	20.6 ± 11.4 a	5
5. 'Hot San Ardo'	12.5 ± 13.6 a	6	16.2 ± 13.0 b	6	28.7 ± 13.7 a	6
7. 'Hot Habanero Orange'	6.8 ± 7.0 a	6	11.7 ± 12.5 b	6	18.5 ± 19.2 a	6
8. 'Red Devil Cayenne'	6.5 ± 4.4 a	6	32.7 ± 31.7 ab	6	39.2 ± 34.3 a	6
9. 'Numex Big Jim'	4.7 ± 3.0 a	6	10.0 ± 4.9 b	6	14.7 ± 7.7 a	6
10. 'Astry'	7.8 ± 5.7 a	6	43.8 ± 27.0 a	6	51.7 ± 29.0 a	6
11. 'Jamaican Yellow'	5.2 ± 4.7 a	6	10.0 ± 4.6 b	6	15.2 ± 7.2 a	6
P[5]	0.4204 NS		0.0396 *		0.0509 NS	

[1]Data are not shown for the first, third, or fourth measurements because they were not significant.
[2]Per plant; different letters indicate significant differences among cultivars based on a Waller-Duncan multiple range test ($P < 0.05$) (SAS institute 2012).
[3]For statistical analyses, all data were transformed by [square root (n + 0.25)] but only non-transformed data are shown.
[4]Number of replications in each group compared.
[5]Significance levels at * $P \leq 0.05$, ** $P < 0.01$, *** $P < 0.001$, and NS (non-significant) were determined by a one-way ANOVA (SAS institute 2012).

organs, which may reflect the longer maturity time (95 days) compared to most other cultivars tested.

The greenhouse tests (Sites A and B) surveyed plant damage and numbers of *S. dorsalis* resulting from adults flying to the plants they chose. However, obtaining good results from adult thrips in Petri dishes would have been difficult because they can escape by flight when counted. The laboratory Petri-dish choice tests (Site C) were limited to larvae, and they provided useful data on *S. dorsalis* responses and plant susceptibilities in a laboratory to complement the greenhouse choice tests. In the field, adults probably do most of the host-plant selection because they are more mobile than larvae; also the use of larvae in choice tests may not be realistic if they differ from adults in preferences. Also, thrips may behave differently on leaf disks than on intact leaves. Chitturi et al. (2006) found that *F. occidentalis* preferred intact tomato plants (*L. esculentum*) over excised leaf disks. The mechanical injury needed to make the disks may have induced jasmonic acid products causing thrips to avoid the disks (Thaler et al. 2001). During each experiment in the laboratory choice test (Site C), we used one set of leaf disks without changing them, and they deteriorated about 10-15 percent by the end of each test. We did not change leaf disks during each experiment because transferring the larvae to new disks may have killed, injured, misplaced, or otherwise disrupted their behavior enough to skew the results more than letting the disks deteriorate a few extra days. In 2 of 3 laboratory choice-test measurements with differences among cultivars (large larvae at 48 h and small larvae at 72 h), 'Agriset 4108' had more larvae per leaf disk than 'Hot Fatalli'. For plants in the greenhouse (Site A), a higher proportion of plants of 'Agriset 4108' than 'Hot Fatalli' were infested with *S. dorsalis*, hence, 'Agriset 4108' apparently had more larvae and adults combined per plant. Despite the leaf deterioration and potentially altered cultivar preferences in leaf-disk tests, the data consistencies between larvae on leaf disks and adults on intact leaves suggested the larvae and adults responded similarly.

The least susceptible cultivar in our study was therefore *C. chinense* 'Hot Fatalli'. On the other hand, in tests of *F. occidentalis* resistance among 2 pepper cultivars by Maris et al. (2004) and 8 cultivars by Fery & Shalk (1991), all lineages were *C. annuum*. In the present study, *C. annuum* 'Hot Habanero Orange' seemed to be the second-least susceptible cultivar and was usually in the lowest statistical grouping for numbers of *S. dorsalis* along with 'Hot Fatalli'. There seem to be non-susceptible cultivars in both *C. annuum* and *C. chinense*, and because they are different species, they may represent independent developments of similar mechanisms.

Because of consistently lower numbers of *S. dorsalis* found on 'Hot Fatalli' than the other cultivars across the 3 tests, it may have been resistant to *S. dorsalis* by antibiosis or nonpreference and not necessarily tolerance. We used only choice tests, however, and preference by *S. dorsalis* for some cultivars may have caused the less-preferred ones to appear resistant, hence, no-choice studies would have provided much stronger evidence for or against resistance.

TABLE 4. NUMBER OF *SCIRTOTHRIPS DORSALIS* LARVAE IN THE LABORATORY CHOICE TEST WITH LEAF DISKS IN LARGE PETRI DISHES (SITE C).

	Large larvae test (beginning with mostly second instars)[1, 2, 3]		Small larvae test (beginning with mostly first instars)[1, 2, 4]	
Cultivar	Time [5]	Mean ± SD	Time [5]	Mean ± SD
1. 'Agriset 4108'	48 h	2.7 ± 1.8 ab	48 h	2.9 ± 2.8 a
2. 'Fresno 6022'	48 h	2.3 ± 2.2 ab	48 h	1.2 ± 1.3 a
3. 'Hot Tormenta',	48 h	1.0 ± 0.6 bc	48 h	2.9 ± 2.5 a
4. 'Hot Fatalli'	48 h	0.2 ± 0.4 c	48 h	0.7 ± 0.9 a
5. 'Hot San Ardo'	48 h	2.8 ± 1.7 ab	48 h	2.6 ± 2.7 a
7. 'Hot Habanero Orange'	48 h	0.5 ± 0.8 c	—	—
8. 'Red Devil Cayenne'	48 h	3.2 ± 1.9 a	48 h	2.2 ± 2.0 a
9. 'Numex Big Jim'	48 h	2.0 ± 1.1 ab	48 h	1.3 ± 1.1 a
10. 'Astry'	48 h	2.0 ± 0.9 ab	48 h	2.1 ± 1.9 a
11. 'Jamaican Yellow'	48 h	1.5 ± 1.2 abc	48 h	2.1 ± 1.9 a
P [6]		0.0027 **		0.2970 NS
1. 'Agriset 4108'	120 h	3.5 ± 2.3 ab	72 h	3.8 ± 3.0 a
2. 'Fresno 6022'	120 h	1.3 ± 1.5 b	72 h	1.0 ± 0.9 b
3. 'Hot Tormenta',	120 h	2.0 ± 1.4 ab	72 h	2.3 ± 2.1 ab
4. 'Hot Fatalli'	120 h	0.8 ± 1.0 b	72 h	0.9 ± 0.9 b
5. 'Hot San Ardo'	120 h	3.2 ± 1.3 ab	72 h	0.9 ± 0.6 b
7. 'Hot Habanero Orange'	120 h	1.7 ± 3.1 b	—	—
8. 'Red Devil Cayenne'	120 h	2.2 ± 3.1 ab	72 h	2.3 ± 2.1 ab
9. 'Numex Big Jim'	120 h	3.5 ± 4.0 ab	72 h	1.3 ± 1.3 ab
10. 'Astry'	120 h	3.0 ± 2.4 ab	72 h	2.0 ± 1.7 ab
11. 'Jamaican Yellow'	120 h	5.2 ± 2.3 a	72 h	3.1 ± 2.7 ab
P [6]		0.0477 *		0.0365 *

[1]Numbers per leaf disk; means within a column followed by the same letter do not differ significantly based on a Waller-Duncan multiple range test ($P > 0.05$) (SAS institute 2012).

[2]For statistical analyses, all data were transformed by [square root (n + 0.25)] but only non-transformed data are shown.

[3]Replications per treatment: 6 (reps 1-6 or 4-9).

[4]Replications per treatment: 9 (reps 10-18).

[5]Hours after placement of larvae onto leaf disks.

[6]Significance levels at * $P \leq 0.05$, ** $P < 0.01$, *** $P < 0.001$, and NS (non-significant) were determined with a one-way ANOVA (SAS institute 2012).

'Fresno 6022' had larger canopy volumes for treated or untreated plants and larger numbers of treated fruit than 'Hot Habanero Orange' or 'Hot Fatalli'. When pesticide treatments were pooled, 'Astry' was higher than 'Hot Habanero Orange' or 'Hot Fatalli' for flowers and total counted organs, and 'Agriset 4108' was higher than 'Hot Habanero Orange' and 'Hot Fatalli' for pedicels. 'Agriset 4108', 'Fresno 6022', and 'Astry' appeared to be some of the highest yielding cultivars in the present study. For 'Fresno 6022', 'Hot Tormenta', 'Cheyenne', 'Astry', and 'Jamaican Yellow' both canopy volume and numbers of fruit were higher for treated than untreated plants, whereas with the other cultivars, only one or none of these variables were higher for treated plants. 'Fresno 6022', 'Hot Tormenta', 'Cheyenne', 'Astry', and 'Jamaican Yellow' therefore seemed to be the most benefitted cultivars by application of spinetoram. Spinetoram seemed to improve yields for "larger" cultivars such as 'Agriset 4108', 'Fresno 6022', 'Hot Tormenta', 'Hot San Ardo', 'Cheyenne', 'Red Devil Cayenne', and 'Astry', which had larger canopy volumes and higher yields than 'Hot Fatalli'. These "larger" cultivars also had and shorter maturity times than 'Hot Fatalli': 70 - 85 days compared to 95 days for 'Hot Fatalli', though maturity times were not compared statistically (Johnny Seeds 2012; Reimer Seeds 2012). Because of the good yields and short maturity times, using spinetoram to control *S. dorsalis* on these cultivars may be more feasible than relying on less-susceptible cultivars with lower infestation rates when untreated, such as 'Hot Fatalli'.

When cultivars were pooled for variables that were non-interacting in the factorial study (Site A), there were no differences between treated and untreated plants for flowers, but pedicels and total counted organs were each higher for treated than untreated plants. The large number of replications (66) obtained by pooling cultivars to compare treatments may have caused overlapping standard deviations despite significant differences between treatments. Hence with cultivars pooled, spinetoram seemed to control *S. dorsalis* sufficiently to increase pedicels and total counted organs, but not flowers.

The canopy volume of 'Hot San Ardo' numerically ranked as the largest for treated plants and the second largest for untreated plants, and that of 'Red Devil Cayenne' ranked as the largest for untreated plants and the fourth largest for treated plants. 'Hot San Ardo' and 'Red Devil Cayenne' had no differences between treated and untreated plants in fruit numbers, and neither canopy volumes or fruit numbers differed between treated and untreated plants for 'Numex Big Jim', which seemed the least affected by spinetoram application. All 3 cultivars had larger treated and untreated canopy volumes than 'Hot Fatalli'. Also, 'Hot San Ardo' and 'Red Devil Cayenne' yielded more treated fruit than 'Hot Fatalli'. Differences in plant size, productivity, and susceptibility to *S. dorsalis* could have been caused by these thrips, cultivar differences, or other factors. 'Hot San Ardo', 'Red Devil Cayenne', and 'Numex Big Jim' each had higher proportions of plants in the initial survey (Site A) that were infested with *S. dorsalis* and more thrips per leaf disk in the 48-h measurement of large larvae (Site C) than cultivars such as 'Hot Fatalli'. Thus, 'Hot San Ardo', 'Red Devil Cayenne', and 'Numex Big Jim' each had high productivities that were often similar between pesticide treatments and larger numbers of *S. dorsalis* than the least productive, least infested cultivar, 'Hot Fatalli'. These cultivars seemed to be sufficiently non-affected by *S. dorsalis* to not benefit from control by spinetoram and may have withstood *S. dorsalis* through tolerance. We did not have multiple measurements of yield and numbers of thrips for each cultivar, which would have been needed to verify tolerance as the resistance mechanism. However, 'Hot San Ardo', 'Red Devil Cayenne' and 'Numex Big Jim' seemed to be in a different response class to *S. dorsalis* by supporting more thrips than 'Hot Fatalli' in one of 2 greenhouse tests and one of 3 measurements of larval tests in the laboratory.

The 11 cultivars can therefore be divided into 3 groups based on their susceptibility to *S. dorsalis* suggested by our study.

Group 1) 'Agriset 4108', 'Fresno 6022', 'Hot Tormenta', 'Cheyenne', 'Astry', and 'Jamaican Yellow'. These cultivars tended to yield the highest fruit numbers, but had high *S. dorsalis* populations when not treated with spinetoram, which seemed to be needed for high yields.

Group 2) 'Hot San Ardo', 'Red Devil Cayenne', and 'Numex Big Jim'. Numerically, yields of these cultivars tended to be more intermediate than cultivars such as 'Fresno 6022', and they tended to have more thrips than 'Hot Fatalli' (the most thrips-free cultivar). However, their resistance mechanism towards *S. dorsalis* may have been tolerance because fruit numbers were not significantly higher for treated than untreated plants.

Group 3) 'Hot Fatalli' and 'Hot Habanero Orange'. 'Hot Fatalli' was in the lowest statistical grouping for yield and number of thrips across the 3 tests, and it seemed to be the lowest yielding but least susceptible cultivar to *S. dorsalis*.

As was suggested by Wardlow (1989) and Fery & Schalk (1991) for developing cultivars resistant to *F. occidentalis*, perhaps through plant breeding, the *S. dorsalis* resistance in 'Hot Fatalli' could be transferred to susceptible but higher yielding cultivars like 'Fresno 6022'. The availability of such resistant cultivars could reduce the need for chemical control, supplement biological control, and possibly become a new focus for integrated management of pests of peppers (Wardlow 1989; Fery & Schalk 1991).

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