Proc. Fla. State Hort. Soc. 128:151–155. 2015.

Management Practices for Controlling Various Thrips and Their Transmitted Tospoviruses in Tomatoes: 1. Chemical Control

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Additional index words. melon thrips, common blossom thrips, western flower thrips, chemical control, tomato, tospoviruses

Thrips are insidious insects having a minute size and excellent hiding capability. They are difficult to see with the naked eye. They are polyphagus and cause serious economic damage by feeding on foliage and transmitting viral pathogens. In south Florida, tomato plants were seriously damaged by tospoviruses vectored by thrips in the 2014–15 vegetable growing season. In our recent survey of commercial tomato fields, we recorded three species of thrips including melon thrips, common blossom thrips and western flower thrips. The latter two species were reported to be the most efficient in transmitting tospoviruses in tomatoes. In an effort to develop an integrated management program for controlling thrips and tospoviruses, we conducted three studies to evaluate insecticides belonging to diverse modes of action under field conditions. In the first study, we used insecticides alone, in combination or in rotation as a foliar spray. In the second study, we used premixed products as foliar sprays. In the third study we used insecticide as a soil drench at planting followed by two drip applications at 14 and 28 days after planting. After four weekly applications in the first study, all insecticide treatments significantly reduced melon thrips as observed in the postspray samples. In the same postspray samples, common blossom thrips and western flower thrips were absent in spinetoram, flonicamid, spirotetramat + spinetoram, clothianidin + malathion, chlorpyrifos, and bifenthrin treated plants. In the second study, melon thrips were significantly reduced by spinetoram followed by cyantraniliprole. In this study, insecticide treatments did not reduce the flower thrips population. Insecticide treatments in the third study did not reduce tospovirus incidence in tomatoes.

Tomato, *Lycopersicon esculentum* Miller, is an important vegetable crop in Florida and is grown on almost 42,000 acres. Miami-Dade County contributes about 8% to total Florida tomato production. Preharvest costs for an acre of fresh market tomato account for approximately $6000 to $7000; 25% of which is related to pest management. Insect pests are an important limiting factor throughout the tomato production season, causing economic damage by feeding and transmitting viral diseases. In a recent survey, we recorded five different species of thrips—melon thrips (*Thrips palmi* Karny), onion thrips (*Thrips tabaci* Lindeman), chilli thrips (*Scirtothrips dorsalis* Hood), common blossom thrips (*Frankliniella schultzei* Trybom), and western flower thrips (*Frankliniella occidentalis* (Pergande).

Melon thrips is an invasive insect that arrived in Miami-Dade County in 1990 (Baranowski, 1990). Since then, it has become an established pest of all vegetable crops except tomato. During the 2014–15 vegetable growing season, its invasion was documented for the first time in all commercial tomato production fields (Seal 2015, field observation). Melon thrips first appears in vegetable crops at the beginning of the growing season (September–October) when plants are 2–4 weeks old. It feeds on vegetable crops throughout the year based on the availability of host crops (Seal, 1996). Melon thrips adults are the first stage to be found on host crops at the beginning of an infestation. Immature stages can be seen within 4–6 d of the adults' arrival. In contrast to other vegetable crops, immature stages of melon thrips could not be found in tomato within 2–4 weeks of the adults' arrival due to its low reproduction rate on this crop. Melon thrips has been reported to transmit tospoviruses in east and south Asian countries (Nagata et al., 2002). It has been reported to transmit calla lily chlorotic spot virus (Chen et al., 2005), groundnut bud necrosis virus (Lakshmi et al, 1995; Meena et al., 2005; Reddy et al., 1992), melon yellow spot virus (Kato et al., 2000), and watermelon silver mottle virus (Iwaki et al., 1984).

Onion thrips are very rare in tomato fields in Miami-Dade County and were observed in one commercial tomato field on only one sampling date (D.R.S., field survey). Chilli thrips arrived in southern Florida in 2005 and were first observed on peppers and roses grown in greenhouses. Later, it spread outside greenhouses and rose to the status of an economic pest of ornamentals, fruits and landscape plants. Chilli thrips are very rare in field grown vegetable crops in the United States. We recorded this thrips in a few tomato samples during the entire tomato growing season. It transmits groundnut bud necrosis virus (German et al., 1992, Meena et al., 2005), peanut chlorotic fan-spot virus (Chen et al.,

Mention of a trademark or proprietary product does not constitute a guarantee, warranty or endorsement by the University of Florida and does not imply its approval to the exclusion of other suitable products. Acknowledgments: C. Sabines assisted with all aspects of this study in fields and the laboratory. Mohammad Razzak helped in collecting samples from fields and processing them to record thrips adult numbers of each species in samples. C. Carter helped maintain the crops.
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1996, Chu et al., 2001), and peanut yellow spot virus (Gopal et al., 2010).

Common blossom thrips was recorded first in 1993 in Miami-Dade County on Mexican prickle-poppy (*Argemone Mexicana*) (Seal and Broda-Hydorn, 1993). Since then, we encountered them inconsistently at a very low number (2–5 per 100 samples) each year. Abundance of this thrips increased in 2008 in vegetable hosts (Kakkar et al., 2012). This thrips is aggressive in transmitting tospoviruses, such as groundnut ring spot virus (GRSV) (Wijkamp et al., 1995; de Bordon et al., 2006; Nagata et al., 2004) and tomato chlorotic spot virus (TCSV) (Londoño et al., 2012; Funderburk et al., 2015; Wijkamp et al., 1995; Nagata et al., 2004). It also transmits chrysanthemum stem necrosis virus (Nagata and de Àévíla, 2000; Nagata et al., 2004) and groundnut bud necrosis virus (Wijkamp et al., 1995). A serious outbreak of tomato chlorotic spot virus (TCSV) on tomato was recorded in Miami-Dade County in the 20014–15 vegetable growing season (Zhang et al., 2015). Its spread has been associated with *Frankliniella schultzei* and *F. occidentalis*.

Western flower thrip is a polyphagous insect feeding on at least 60 plant families. Among these, beans, cucumber, eggplant, lettuce, onion, pepper, tomato, watermelon, and various ornamentals are important hosts of western flower thrips. It is active in transmitting various tospoviruses which include chrysanthemum stem necrosis virus (Nagata and de Àévíla, 2000; Nagata et al., 2004), groundnut ring spot virus (Wijkamp et al., 1995; Nagata et al., 2004), impatients necrotic spot virus (De Angelis et al., 1993; Wijkamp et al., 1995; Sakurai et al., 2004), tomato chlorotic spot virus (Wijkamp et al., 1995; Nagata et al., 2004) and tomato spotted wilt virus (TSW) (Medeiros et al., 2004; Wijkamp et al., 1995; Nagata et al., 2004)

In the present project, we have conducted research studies on the management of melon thrips, common blossom thrips, and western flower thrips. Specifically, we will report on the effectiveness of various insecticides belonging to different modes of action in managing the above mentioned thrips in tomato.

Materials and Methods

Thrips belonging to three different species (*T. palmi*, *F. occidentalis* and *F. schultzei*) are significant pests of tomato in the south Florida. Among these, common blossom thrips and western flower thrips are aggressive in vectoring GRSV and TCSV. Melon thrips role in transmitting tospoviruses is not clear. The effectiveness of various chemical insecticides has been evaluated for controlling the above mentioned thrips in three studies in tomatoes. Two studies were conducted in a Tropical Research and Education Center (TREC) research field in Homestead, FL, and one study was conducted in a commercial field in Miami-Dade County, FL. In all studies the soil type was Krome gravelly loam (loamy-skeletal, carbonated hyperthermic Lithic Udorthents), which consisted of 33% soil and 67% pebbles (> 2 mm). 'FL 47' tomato transplants were planted on raised beds 91 cm wide and 15 cm high covered with 1.5 mm thick black-and-white polyethylene mulch. Tomato seedlings were placed in 1.5 cm deep holes spaced 45.72 cm (18 inches) within the row and 1.83 meters (72 inches) between adjacent rows. A pre-plant herbicide, halosulfuron methyl (Sandea®, Gowan Company LLC., Yuma, Arizona) was applied at 51.9 g/ha 21 days before planting to control weed emergence. Crops were fertilized applying granular fertilizer (6N–12P–12K) at 1345 kg/ha in a 10 cm-wide band on both sides of the raised bed center and was incorporated before placement of the plastic mulch. Additionally, liquid fertilizer (4N–0P–8K) was also applied at 0.56 kg/ha/day through a drip system at 2, 3, 4, and five weeks after planting. Plants were irrigated every day for one hour using two parallel lines of drip tube (T-systems, DripWorks, Inc., Willits, California), spaced 30 cm apart parallel to the bed center and having an emitter opening for water every 13 cm. For managing fungal pathogens, chlorothalonil (Bravo®, Syngenta Crop Protection, Inc., Greensboro, NC) at 1.75 L/ha and copper hydroxide (Kocide® 3000, BASF Ag Products, Research Triangle Park, NC) at 0.8 L/ha were sprayed every two weeks.

In each study, treatment plots consisted of two beds each 12.19 m (40 ft.) long x 0.91 m (3 ft) wide. Plots were arranged in a randomized complete-block design replicated four times. A 1.52 m (5 ft) planted space separated adjacent plots in a block. Thus, each block consisted of 161.5 m (530 ft) long two beds. One planted bed separated each block from the next block. Altogether the experimental area consisted of 11 beds.

First Study

For the first study in a commercial field, 'FL 47' tomato transplants were set on 12 Nov. 2014 using the cultural practices described above. The twelve treatments applied in this study included: 1. cyantraniliprole (21.4 oz/acre, Exirel®, IRAC Group 28, Dupont USA); 2. spinetoram (8.0 oz/acre, Radiant® SC, IRAC Group 5, Dow AgroSciences, Indianapolis, IN); 3. bifenthrin (Brigade® 2 EC) premixed with imidacloprid (Admire® Pro) (5.0 oz/acre, Brigadier); 4. dinotefuran (5 oz, Venom®, IRAC Group 4A, Valent USA Corporation) in combination with spinetoram (8 oz/acre, Radiant® SC, IRAC Group 5, Dow AgroSciences); 5. acetamiprid (6.0 oz, Assail® 30 SG, IRAC Group 4A, Nippon Soda Co., LTD.); 6. flonicamid (4.0 oz./acre, Beleaf® 50 SG; IRAC Group 9, FMC); 7. spirotetramat (5.0 oz/acre, Movento®, IRAC Group 23, Bayer Crop Science, North Carolina); 8. clothianidin (6.0 oz/acre, Belay®, IRAC Group 4A, Valent USA) in combination with malathion (32.0 oz/acre, Malathion® 8 E, IRAC Group 1B, Loveland, Colorado); 9. chlorpyrifos (16 oz/acre; Lorsban® 4 E, IRAC Group 1B, Dow AgroSciences); 10. abamectin (16.0 oz/acre; Agrimek®, IRAC Group 6, Syngenta Crop Protection, USA); 11. bifenthrin (2.5 oz/acre, Brigade® 2 EC, IRAC Group 3A, FMC, Memphis, TN); and 12. a nontreated control. All insecticide treatments were applied four times at 7-d intervals on 24 Dec. 2014, and 1, 8, and 15 Jan. 2015, using a backpack sprayer with two flat fan nozzles (Sprayer Outlet, 1035 Sylvatus Highway, Hillsville, VA) delivering a volume of 50–70 GPA depending on the canopy volume. Evaluation of treatments for thrips control was made by collecting leaf and flower samples 48 h after each spray application. The results show prespray and last spray counts. Sampling was accomplished by collecting randomly selected one full grown young leaf per plant from 10 randomly selected plants in each treatment plot. At the flowering stage, flower samples were also collected following the same method as leaf samples. Samples were then placed in thrips-proof one quart plastic cups marked with the date, block and treatment number. Sample cups were transported to the vegetable IPM Laboratory at TREC. Leaves in each plastic cup were soaked with 100 cc 70% ethanol for 20 min to dislodge thrips larvae and adults from leaves. Each leaf was then taken out by gently swirling it to avoid any loss of the thrips. This method allowed the thrips to stay in the alcohol solution while the leaves were taken out. The remaining contents of each cup (70% Ethanol + thrips) were then passed through a 200 mesh nematode separating sieve (U.S. Standard sieve series, no. 200, Fisher Scientific Company). All the contents of the sieve were transferred to a Petri dish for recording thrips by species using a binocular microscope at 10X magnification. A similar method was used for flower samples. Due to the low number of common blossom thrips and western flower thrips, they were counted together as flower thrips.

Second Study

In the second study, 'FL 47' tomato transplants were planted on 15 Dec 2014, at a TREC research plot. Various treatments evaluated in this study included: 1) three formulations of A21390 (A21390a, A21390b and A21390c) which are combinations of abamectin (Agrimek®, IRAC Group 6, Syngenta Crop Protection, USA) and cyantraniliprole (Exirel®, IRAC Group 28, Dupont, USA). Each formulation of A21390 was sprayed at 8.0 oz/acre; 2) spinetoram (8.0 oz/acre, Radiant® SC, IRAC Group 5, Dow AgroSciences, Indianapolis, IN); 3) thiamethoxam (Actara®, IRAC Group 28, Syngenta Crop Protection, USA) premixed with chlorantraniliprole (Coragen®, IRAC Group 28, Dupont, USA) (13.0 oz, Durivo®, Syngenta Crop Protection, USA); 4) cyantraniliprole (21.4 oz./acre, Exirel®, IRAC Group 28, Dupont, USA); and 5) a nontreated control. All treatments in this study were applied as a foliar spray. Methods for crop planting, management, treatments application, sampling and sample preparation were as described above in the first study.

Third Study

'FL 47' tomato transplants were set on 29 Dec. 2014 in a TREC research field. Diamide (IRAC Group 28) and neonicotinoid (IRAC Group 4) insecticides were used to control thrips and thrips transmitted tospoviruses in tomato. Field management, bed preparation, and practices for crop planting, management, and sampling were as described in the first study. Six treatments used in this study included: 1) imidacloprid (16 oz/acre, Admire® Pro, IRAC Group 4, Bayer Crop Science, North Carolina) at planting as a soil drench followed by two drip applications of cyantraniliprole (13.5 oz/acre, Verimark® SC, IRAC Group 28, Dupont USA) 14 and 28 days after planting; 2) imidacloprid (16 oz/acre) at planting as a soil drench followed by two drip applications of chlorantraniliprole (5.0 oz/acre, Coragen® SC, IRAC Group 28, Dupont USA) 14 and 28 days after planting; 3) imidacloprid (16.0 oz/acre, Admire® Pro) at planting as a soil drench; 4) cyantraniliprole (13.5 oz/acre, Verimark®) at planting as a soil drench; 5) cyantraniliprole (13.5 oz/acre, Verimark®) at planting as a soil drench followed by drip application of imidacloprid (16 oz/acre, Admire® Pro) 14 days after planting; and 6) a nontreated control.

Treatment plots consisted of two 40 feet long beds arranged in a randomized complete-block design with four replications. Treatments were evaluated by counting TCSV infected plants in each treatment plot 14, 21, and 42 days after planting.

Statistical Analysis

Data on the abundance of various thrips species adults collected from treated samples were transformed using square-root of $X + 0.25$ before performing an analysis of variance (ANOVA). The transformed data were analyzed by least squares ANOVA (PROC GLM, SAS Institute 1989). However, for ease of interpretation, the means of the original data were presented in the table.

Results and Discussion

First Study

Melon Thrips. Population abundance of melon thrips, *Thrip palmi* Karny, was fairly high (Fig. 1). In the prespray samples, all plants in treatment plots had melon thrips adults (mean 2.8–8.2) with a wide range of variation although numbers in different treatments did not differ statistically from the nontreated control ($F = 0.38$, df = 11,24; $P = 0.05$). The final samples, collected after four weekly application of each insecticide treatment, showed a reduction in the number of melon thrips adults when compared with the respective prespray counts. When postspray counts of all treatments were considered, clothianidin + malathion, dinotefuran + spinetoram, spirotetramat + spinetoram, and chlorpyrifos did not differ from the nontreated control in the mean numbers of melon thrips adults. When the percentage reduction of adults based on prespray numbers and last sample numbers after four weekly applications were considered, it was the highest in bifenthrin treated plants (76%) followed by acetamiprid + Chlorpyrifos. The percentage reduction was significant in all insecticide treatments when compared with the nontreated control (Fig. 2). In the nontreated plants, the melon thrips population increased and in the insecticide treated plants the melon thrips population decreased.

Flower Thrips. In the present study, both common blossom thrips and western flower thrips are presented together as `Flower thrips.' Flower thrips occurrence was recorded in all plots before the initiation of insecticide application (Fig. 3). After spraying insecticide treatments, flower thrips were absent in spinetoram, flonicamid, spirotetramat + spinetoram, clothianidin + malathion, chlorpyrifos and bifenthrin treated plants. In other treatments, except bifenthrin premixed with imidacloprid (Brigadier®), mean numbers of flower thrips adults in the postspray samples were significantly fewer than in the prespray samples.

Second Study

Melon Thrips. Melon thrips adults were recorded on all tomato plants in prespray samples (Fig. 4). Mean numbers of adults/leaf sample varied from 4.50–6.75 irrespective of treatment plots. A significant reduction in the mean numbers of melon thrips adults

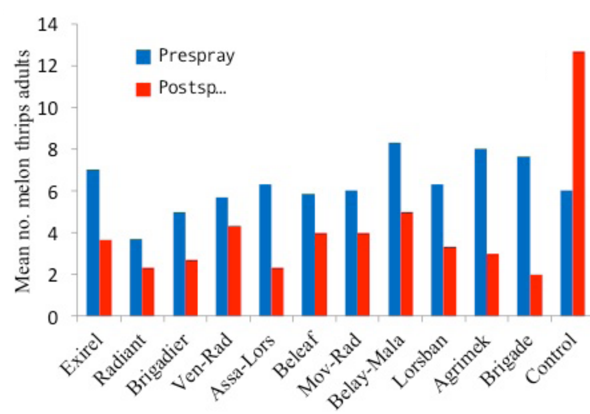

Fig. 1. Mean numbers of melon thrips adults in various tratment plots at pre-and postspray samples in a commercial tomato field, 2014–2015. Prespray: $F = 0.34$; df = 11, 24; $P > 0.05$. Postspray: $F = 2.69$, df = 11, 24; $P > 0.05$. Exirel (cyantraniliprole), Radiant (spietoram), Brigadier (bifenthrin premixed with imidacloprid, Ven-Rad (dinotefuran+spinetoram), Assa-Lors (acetamiprid+chlorpyrifos), Beleaf (flonicamid), Mov-Rad (spirotetramat+spinetoram), Belay-Mala (clothianidin+malathion), Lorsban (chlorpyrifos), Agrimek (abamectin), Brigade (bifenthrin).

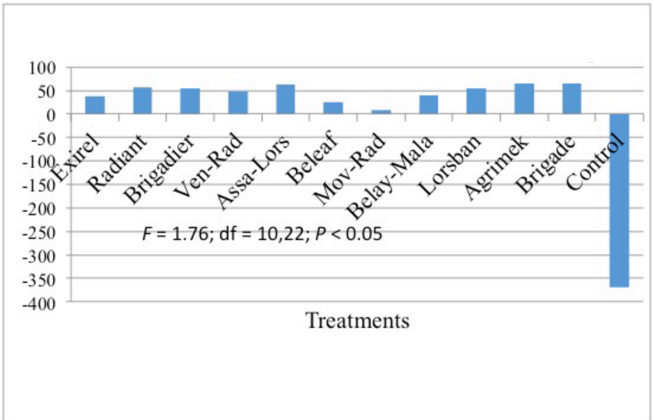

Fig. 2. Percent reduction of melon thrips adults after four weekly foliar application of various insecticides in tomatoes. F = 1.76; df = 11, 24; P < 0.05. Exirel (cyantraniliprole), Radiant (spinetoram), Brigadier (bifenthrin premixed with imidacloprid, Ven-Rad (dinotefuran+spinetoram), Assa-Lors (acetamiprid+chlorpyrifos), Beleaf (flonicamid), Mov-Rad (spirotetramat+spinetoram), Belay-Mala (clothianidin+malathion), Lorsban (chlorpyrifos), Agrimek (abamectin), Brigade (bifenthrin).

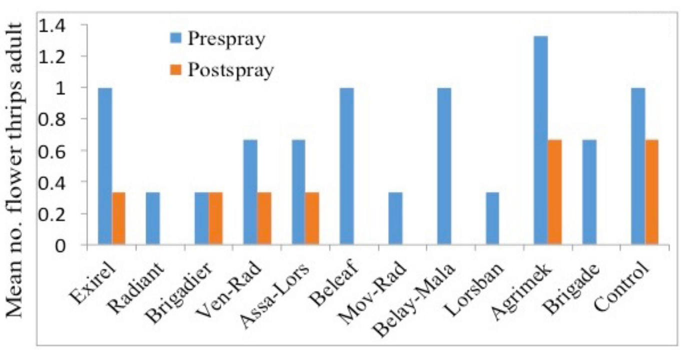

Fig. 3. Mean numbers of adult flower thrips adult in various treatment plots at pre- and postspray samples in a commercial tomato field 2014–2015. Prespray: F = 0.0.50; df = 11, 24; P > 0.05. Postspray: F = 1.06; df = 11, 24; P >0.05. Exirel (cyantraniliprole), Radiant (spinetoram), Brigadier (bifenthrin premixed with imidacloprid, Ven-Rad (dinotefuran+spinetoram), Assa-Lors (acetamiprid+chlorpyrifos), Beleaf (flonicamid), Mov-Rad (spirotetramat+spinetoram), Belay-Mala (clothianidin+malathion), Lorsban (chlorpyrifos), Agrimek (abamectin), Brigade (bifenthrin).

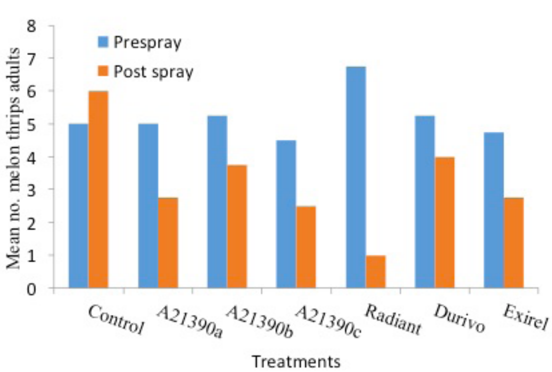

Fig. 4. Mean numbers of melon thrips adults in various treatment plots at pre- and postspray samples in a TREC research field, 2014–2015. Prespray: F = 1.11; df = 6, 21; P ≥ 0.05. Postspray: F = 3.22; df = 6, 21; P > 0.05. A21390 (abamectin premixed with cyantrabiliprole), Radiant (spinetoram), Durivo (thiamethoxam premixed with chlorantraniliprole).

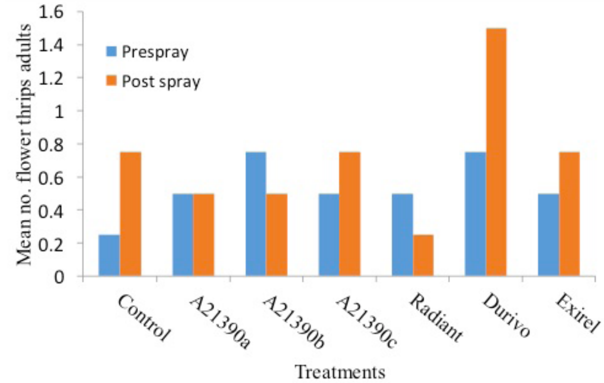

Fig. 5. Mean numbers of adult flower thrips in various treatment plots at pre and postspray samples in a commercial tomato field, 2014–2015. Prespray: F = 0.18; df = 6, 21; P ≥ 0.05. Postspray: F = 0.79; df = 6, 21, P > 0.05. A21390 (abamectin premixed with cyantrabiliprole), Radiant (spinetoram), Durive (thiamethoxam premixed with chlorantraniliprole).

per sample treated with various insecticides was observed when compared with the nontreated control. However, the mean number of melon thrips adults per sample in A21390b and Durivo treated plants did not differ significantly from the nontreated control. Spinetoram treated plants had the lowest number of melon thrips adults followed by A21390c followed by A21390a.

Flower Thrips. Flower thrips population density was low during this study (Fig. 5). However, we recorded flower thrips adults in all treatment plots. Mean numbers of adults in treated samples were variable (range: 0.5–1.0), and did not differ from the nontreated control. Mean number of adults in the Durivo treated plants increased in the postspray sample as compared to the prespray sample. The mean number of flower thrips adults did not differ between pre- and postspray samples treated with A21390a and A21390b. In other treatments (A21390b, spinetoram and cyantraniliprole), mean numbers of flower thrips adults decreased as compared to the prespray sample.

Third Study

The third study was conducted to determine the effectiveness of insecticide treatments in controlling TCSV incidence in tomato plant (Fig. 6). TCSV incidence was recorded in all treatment plots

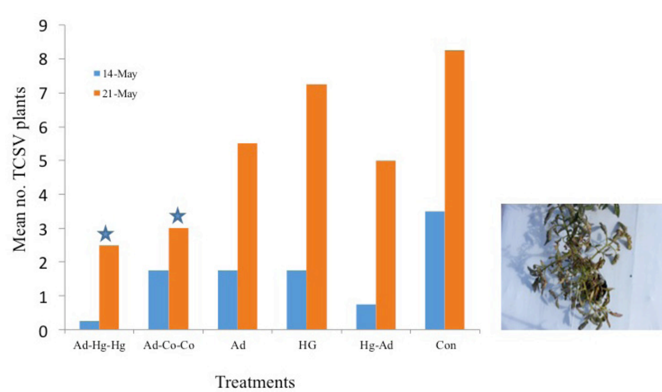

Fig. 6. Mean numbers of tomato plants showing GRSV/TCSV incidence on three sampling dates treated with various insecticides. Ad-Ve-Ve (imdacloprid-cyantraniliprole-cyantraniliprole), Ad (imidacloprid), Ve (verimark), Ve-Ad (verimark-(imidacloprid).

14 days after planting. At this time (14 DAP), mean numbers of infected plants were significantly fewer in all treated plots as compared to the nontreated control. The number of infected plants increased as the days after planting progressed. 21 days after planting, the mean number of infected plants was significantly lower in plots treated with imidacloprid followed by two drip applications of cyantraniliprole, and imidacloprid followed by two drip applications of chlorantraniliprole as compared to the nontreated control. Other treatments did not differ from the non-treated control in terms of the number of tospovirus infected plants. Forty-two days after planting, almost all tomato plants in all treatment plots were infected with tospoviruses and did not differ staticsally from the nontreated plants.

Summary

In summary, melon thrips, common blossom thrips, and western flower thrips were present in all tomato fields infected with tomato chlorotic spot virus (TCSV). There were more melon thrips than flower thrips based on both leaf and flower samples. Spinetoram was effective in controlling all three species of thrips on tomatoes with few exceptions. Neonicotinoid and diamide insecticides applied in a rotation program showed effectiveness in controlling all thrips in the present study. Although insecticides were effective in suppressing thrips populations, they did not reduce the incidence of TCSV in tomatoes. As a result, almost all tomato plants in various treatment plots showed signs of tospovirus infection six weeks after planting in the third study. Further research studies are warranted to study the biology of thrips species in association with TCSV. More insecticides of various modes of action should be evaluated alone, in rotation or in combination as a tank mix for usein managing thrips and TCSV. Information on alternate hosts of melon thrips, common blossom thrips and western flower thrips will be important devising an effective management program.

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