Efficacy of Insecticides and Bio-pesticides for Control of Greenhouse Whitefly on Tomatoes in Greenhouses in India[1]

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ABSTRACT The greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae), is a major insect pest of tomato under field and greenhouse conditions, and its management is based primarily on foliar applications of insecticides. However, the continuous use of conventional insecticides leads to the development of insecticide resistance, which emphasizes the need for new pest management alternatives. The present study was conducted to investigate the efficacy of insecticides and bio-pesticides against the greenhouse whitefly on tomatoes grown in polyhouses (plastic-covered greenhouses) for two years at Palampur, Himachal Pradesh, India. Results showed that abamectin resulted in the highest mean percent reduction in immatures of *T. vaporariorum*, followed by acetamiprid and buprofezin. Spiromesifen and bifenthrin resulted in moderate levels of efficacy, followed by azadirachtin and mineral oil. Spinosad, *Melia*, and malathion (the insecticide-treated control) showed the least efficacy against immatures of *T. vaporariorum*. Similarly, abamectin and acetamiprid were the most highly effective materials against the adult stage. Bifenthrin, spinosad, azadirachtin, and buprofezin showed moderate reductions in adult whitefly populations. Spiromesifen, mineral oil, *Melia*, and malathion were the least effective against adult populations of *T. vaporariorum*. Overall, abamectin, acetamiprid, buprofezin, and bifenthrin were the most promising materials for managing *T. vaporariorum* in greenhouses. Azadirachtin and mineral oil also provided adequate control of greenhouse whitefly on greenhouse tomatoes.

KEY WORDS *Trialeurodes vaporariorum*, polyhouse, abamectin, acetamiprid, buprofezin, azadirachtin

India has immense potential for the export of high-value vegetables and flowers, in addition to meeting the increasing demands of the domestic market for these commodities (Pathania 2012). Thus, there is a need to increase the productivity and quality of produce in order to fulfil the demands of quality-conscious consumers. Modern greenhouse technology (or protected cultivation) has provided a breakthrough in expertise that integrates market-driven quality parameters with production systems that ensure a vertical growth in productivity.

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In India, growing vegetable and floriculture crops under protected cultivation has received considerable attention recently, and greenhouse production is gaining popularity among the farming community. The government of India has launched various schemes for promoting protected cultivation through the National Horticulture Board (Singh 2015), and a large number of polyhouses (plastic-covered greenhouses) have been built in the Indian States of Kerala, Himachal Pradesh, Karnataka, Maharashtra, North Eastern Hill Region, Haryana, Gujarat, Tamil Nadu, Andhra Pradesh, and the National Capital Region. This has assured higher crop productivity both in terms of quality and quantity of the produce.

Among vegetable crops, tomato, *Solanum lycopersicum* L. (Solanaceae), is mostly cultivated in open field conditions. However, it also is one of the most preferred crops being grown in greenhouses worldwide in order to achieve year-round production of quality tomatoes (Singh 2005). Tomatoes, worldwide, are grown on over 4.7 million hectares under open and protected conditions, with a total world production of nearly 164 million tons in 2013 (Anonymous 2015a). India is second, after China, with total production of 18.7 million tons of tomatoes grown on nearly 0.9 million hectares. India exported 0.43 million tons of tomatoes in 2013-2014 (Saxena & Gandhi 2015).

Under protected cultivation, vegetable crops are mainly affected by biotic factors that include insects, mites, and diseases. Major insect and mite pests in greenhouses belong to the orders Hemiptera (aphids, whiteflies, and mealybugs), Thysanoptera (thrips), Diptera (leaf miners), and Acari (mites) (Papasolomontos 2004, Perdikis et al. 2008, Mehta 2012). Among these pests, the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae), causes serious economic damage to tomato crops being grown under greenhouse conditions. This pest was first recorded in India from the Nilgiri Hills of Tamil Nadu on potato, *Solanum tuberosum* L. (Solanaceae) (David 1971), and, subsequently, it has been recorded on 101 plants from India, of which 55 host plants are found in Himachal Pradesh (Mohan et al. 1988, Chandramohan & Nanjan 1992, Dhillon 1999, Krishnan & David 1999, Sood & Sood 2002, Bakshi et al. 2003).

The presence of greenhouse whiteflies on the underside of leaves, their rapid multiplication rate, wide distribution, and broad host range add to the difficulties in their management (Johnson et al. 1982). The main method for managing whiteflies is the use of insecticides. However, the intensive use of pesticides has polluted the environment, harmed human beings, destroyed non-target organisms, caused a deterioration in the quality of produce, and led to the development of resistance in pests (Kulat et al. 1999, Raj 2003). Research on bio-pesticides effective against whiteflies under protected cultivation is limited. Therefore, the present investigation was devised to evaluate the efficacy of insecticides and bio-pesticides against whitefly under protected cultivation.

Materials and Methods

Experimental trials. 'Avtar' tomato (hybrid) was sown in a modified, naturally ventilated Quonset polyhouse (250 m^2) at the Experimental Farm, Department of Entomology, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, India. The experiment was repeated in 2010 and 2011, and it was laid out in a randomized block design with three replications for

Table 1. Details of the insecticides and bio-pesticides used in the study.

Insecticide/ Bio-pesticide	Chemical group	Formulation	Manufacturer/Source
Abamectin	Avermectins	Abacin 1.9 EC	Crystal Phosphates Ltd., New Delhi, India
Acetamiprid	Neonicotinoids	Pride 20 SP	Dow AgroSciences India Pvt. Ltd., Mumbai, India
Azadirachtin	Botanicals	Neemazal-TIS 1 EC	E.I.D. Parry India Ltd., Chennai, India
Bifenthrin	Pyrethroids	Talstar 10 EC	FMC India Pvt. Ltd., Bangalore, India
Buprofezin	Thiadiazines	Ben 25 EC	Nagarjuna Agrichem Ltd., Hyderabad, India
Malathion	Organophosphates	Malathion 50 EC	Insecticide India Ltd., Rajasthan, India
Melia-based formulation[a]	Botanicals	SMHEO-4	Division of Agro Chemicals, IARI, New Delhi, India
Mineral oil	Oils	Servo Agrospray T	Indian oil corporation, Mumbai, India
Spinosad	Spinosyns	Success 2.5 SC	Dow AgroSciences India Pvt. Ltd., Mumbai, India
Spiromesifen	Tetronic acids	Oberon 240 SC	Bayer CropScience, Mumbai, India

[a]Extract from *Melia azedarach* L. (Meliaceae).

each treatment. Experimental plots were 1.0 × 2.4 m, and tomato seedlings were planted in double rows with 60 × 75 cm spacing around each plant, and thus each plot accommodated eight plants.

Insecticides and bio-pesticide. Spray treatments were abamectin (0.004% concentration), acetamiprid (0.008%), azadirachtin (0.0025%), bifenthrin (0.004%), buprofezin (0.02%), malathion (0.05%), a *Melia*-based botanical (0.025%) (extract from *Melia azedarach* L. [Meliaceae]), mineral oil (0.5%), spinosad (0.003%), spiromesifen (0.023%), and water (untreated control) (Table 1). The whitefly-infested tomato plots were sprayed once 45 days after planting using a battery-operated knapsack sprayer at 5.62 kg/cm^2 pressure until runoff.

Observations. Pre-treatment counts of immature stages (nymphs and pupae) and adults were recorded from five randomly selected plants (44 days after planting) in each plot one day before spraying. Post-treatment counts of immature stages (nymphs and pupae) and adults were recorded 1, 3, 7, 10, and 15 days after spraying (DAS). Three leaves each from the upper, middle, and lower canopy of the selected plants were collected and brought to the laboratory for counting immatures using a Nikon SMZ745T stereoscopic zoom microscope (Nikon Instruments Inc., Tokyo, Japan), as described by Sangha et al. (1995) and adopted by Sood (2002). The adult population was monitored by counting them *in-situ* during early morning hours.

Statistical analysis. Post-spray data were expressed as the percent reduction from the untreated controls, while original counts were used for pre-spray data. Data were pooled for the 2010 and 2011 experiments and then subjected to analysis of variance (ANOVA), followed by mean separation using the protected least significant difference (LSD) test at the 0.05 level of significance (Gomez & Gomez 1984). The analysis was performed through IBM SPSS Software (version 16.0) (Anonymous 2016).

Results

Insecticide efficacy against immature stages. Significant differences were observed in reduction of whitefly populations among treatments at different days after spray (Table 2). Before spraying, the whitefly population showed non-significant differences among treatments, and populations ranged from 17.8 to 24.0 nymphs and pupae per three leaves. In the untreated control, the whitefly population varied from 18.0 to 27.2 nymphs and pupae per three leaves throughout the observation period. Overall, abamectin showed the highest percent reduction (92.4%) of immatures, followed by acetamiprid (89.6%) and buprofezin (82.8%), which were not statistically different from each other. Spiromesifen and bifenthrin resulted in 80.1% and 77.6% reductions in population, respectively. Population reductions by azadirachtin (69.4%) and mineral oil (68.4%) were statistically similar. The lowest percent reduction in immature populations were for *Melia* (56.2%), malathion (insecticide-treated control) (43.2%), and spinosad (42.1%) (Table 2).

Insecticide efficacy against adult stage. There were significant differences in reduction of whitefly adults among treatments at different days after spray (Table 3). One day before spraying, the whitefly population ranged from 12.7 to 19.9 adults per three leaves, which was statistically non-significant. The whitefly population in the untreated control ranged from 7.7 to 12.2 adults per three leaves throughout the study. The most effective treatment was abamectin, which resulted in the highest mean percent reduction (91.5%), followed by acetamiprid (89.9%), bifenthrin (87.7%), and spinosad (76.9%). Azadirachtin, buprofezin, and mineral oil had statistically similar reductions of adult populations at 74.1%, 73.5%, and 73.2%, respectively. Spiromesifen reduced adult populations by 68.5%. However, *Melia* (51.1%) was statistically equal to the insecticide-treated control (malathion, 53.0%).

Discussion

The insecticides and bio-pesticides used in this study belong to different chemical groups and, thus, possess different modes of action. However, all of the materials evaluated had some effectiveness in reducing whitefly populations on greenhouse-grown tomatoes. Abamectin, an avermectin active at the chloride channel (Anonymous 2015b), resulted in the highest reduction of immatures and adults of the greenhouse whitefly in this study. Several studies substantiate the effectiveness of abamectin for whitefly control. For example, Kumar & Poehling (2007) reported on the effectiveness of abamectin against the sweetpotato whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), on tomato under greenhouse conditions. Saad et al. (2007) showed high efficacy of abamectin against adults and immatures of *B. tabaci* in field beans. Peric et al. (2009) also recorded

Table 2. Efficacy of insecticides and bio-pesticides on immature stages of *Trialeurodes vaporariorum* in greenhouses in India during 2010 and 2011 (pooled data).

Treatment (Percent concentration)	Pre-count (1 DBS)[a]	Percent reduction in population over untreated control					
		1 DAS[b]	3 DAS	7 DAS	10 DAS	15 DAS	Pooled mean
Abamectin (0.004%)	23.3	96.2	94.0	93.0	91.2	87.5	92.4
Acetamiprid (0.008%)	20.9	98.2	93.5	89.9	85.1	81.3	89.6
Azadirachtin (0.0025%)	18.6	74.9	75.1	70.7	67.3	59.1	69.4
Bifenthrin (0.004%)	16.8	85.1	81.8	79.6	74.5	67.2	77.6
Buprofezin (0.02%)	17.8	78.1	81.8	88.6	85.2	80.3	82.8
Malathion (0.05%) (Insecticide-treated control)	21.1	61.6	51.6	36.9	41.0	24.9	43.2
Melia (SMHEO-4) (0.025%)	23.5	74.5	71.1	62.5	45.3	27.6	56.2
Mineral oil (0.5%)	23.2	77.9	74.6	69.2	63.9	56.6	68.4
Spinosad (0.003%)	21.5	56.3	50.2	45.3	40.1	32.9	45.0
Spiromesifen (0.023%)	24.0	72.3	81.4	84.4	82.4	80.1	80.1
LSD (P = 0.05)	NS[c]	4.7	5.1	3.9	9.3	7.9	8.3
Water (Untreated control)[d]	23.4	21.9	18.0	20.5	25.2	27.2	—

[a]Number of nymphs and pupae/three leaves one day before spraying (DBS).
[b]DAS = Days after spraying.
[c]NS = Non-significant at 5 percent level of significance.
[d]Mean number of nymphs and pupae at indicated days after spraying (DAS).

Table 3. Efficacy of insecticides and bio-pesticides on adults of *Trialeurodes vaporariorum* in greenhouses in India during 2010 and 2011 (pooled data).

Treatment (Percent concentration)	Pre-count (1 DBS)[a]	Percent reduction in population over untreated control					
		1 DAS[b]	3 DAS	7 DAS	10 DAS	15 DAS	Pooled mean
Abamectin (0.004%)	14.8	95.2	94.5	92.6	90.3	84.9	91.5
Acetamiprid (0.008%)	15.0	94.8	93.5	90.8	88.3	82.1	89.9
Azadirachtin (0.0025%)	14.2	79.1	77.6	74.4	72.1	67.6	74.1
Bifenthrin (0.004%)	12.7	92.8	92.0	88.6	86.2	78.7	87.7
Buprofezin (0.02%)	14.9	69.4	73.8	78.6	74.9	70.7	73.5
Malathion (0.05%) (Insecticide-treated control)	18.0	67.2	58.7	51.4	46.3	41.7	53.0
Melia (SMHEO-4) (0.025%)	13.1	71.8	64.4	54.4	38.7	26.1	51.1
Mineral oil (0.5%)	19.9	77.1	74.9	74.1	71.2	68.7	73.2
Spinosad (0.003%)	15.3	85.0	84.0	78.3	72.4	64.8	76.9
Spiromesifen (0.023%)	18.1	77.5	73.0	68.9	67.6	55.7	68.5
LSD ($P = 0.05$)	NS[c]	5.4	5.2	7.3	4.6	8.4	7.3
Water (Untreated control)[d]	12.2	11.1	7.7	7.9	7.9	8.9	—

[a]Number of adults/three leaves one day before spraying (DBS).
[b]DAS = Days after spraying.
[c]NS = Non-significant at 5 percent level of significance.
[d]Mean number of adults at indicated days after spraying (DAS).

large reductions of *T. vaporariorum* populations using abamectin in glasshouse tomatoes.

Acetamiprid, a neonicotinoid, caused reductions of immatures and adults of *T. vaporariorum* that were not significantly different from abamectin. This is supported by Zabel et al. (2001), who reported similar results for managing *T. vaporariorum* on tomato. In addition, Barrania & Abou-Taleb (2014) reported that neonicotinoids, including acetamiprid, and chitin synthesis inhibitors, such as buprofezin, resulted in the greatest reductions of *B. tabaci* on cotton.

Buprofezin, a chitin synthesis inhibitor, has been found to be effective against immature stages of *B. tabaci* (Beevi & Balasubramanian 1991, Kandil et al. 1992). In the present investigation, buprofezin showed a greater reduction of immature whiteflies than adults. These findings are substantiated by Mohd-Rasdi et al. (2012), who concluded that buprofezin significantly reduced immatures of *T. vaporariorum* on tomato and brinjal (eggplant).

Spiromesifen, a spirocyclic phenyl-substituted tetronic acid which acts on acetyl CoA carboxylase, was found effective against *B. tabaci* (Nauen et al. 2002, Mann et al. 2012). In the present study, spiromesifen was more effective against immatures than adults. Bi & Toscano (2007) also observed higher toxicity of spiromesifen against eggs and different nymphal instars compared with adults of *T. vaporariorum* in strawberry.

Marcano & Gonzalez (1993) recorded the highest efficacy against *B. tabaci* on tomato by imidacloprid (neonicotinoid), followed by buprofezin and bifenthrin, which substantiates the present findings. The present study showed that bifenthrin, a synthetic pyrethroid, produced a higher reduction of adults than immatures of *T. vaporariorum*, which agrees with the report of Palumbo (2008). In addition, Jamieson et al. (2010) showed that bifenthrin was among the most effective insecticides tested against immatures and adults of the Australian citrus whitefly, *Orchamoplatus citri* (Takahashi) (Hemiptera: Aleyrodidae).

Among the botanicals, extracts from *Azadirachta indica* A. Juss. (Meliaceae) (neem) and *Melia azedarach* L. (Meliaceae) have been reported to be effective against *B. tabaci* (Hammad et al. 2000, 2001, Hammad & McAuslane 2006, Bleicher et al. 2007, Lynn et al. 2010, Nzanza & Mashela 2012, Solangi et al. 2014). In the present study, the active component in neem, azadirachtin, was more effective against *T. vaporariorum* than a *Melia*-based formulation. Similarly, Kumar & Singh (2014) observed that neem formulations were more toxic than dharek extract (*Melia azedarach* L.) against *T. vaporariorum* on tomato.

The efficacy of mineral oil against various whiteflies on citrus, tomato, and pepper has been studied by several workers (Stansly & Liu 1995, Stansly & Conner 2005, Jamieson et al. 2010), and mineral oil was effective in reducing these populations. Legaspi & Simmons (2012), while studying the commercial oils as oviposition deterrents, found significant reduction in whitefly egg counts. In the present investigation, mineral oil was found effective in reducing immatures and adults of *T. vaporariorum*.

Spinosad, a spinosyn, was less effective against immatures than it was against adults of *T. vaporariorum*. These findings are substantiated with Shafie & Abdelraheem (2012) who also reported a lower efficacy of spinosad compared with neem-based formulations.

Malathion, an organophosphate, was used as the insecticide-treated control. It was the least effective material tested against *T. vaporariorum* on tomato.

However, Adamou et al. (2014) observed that malathion, at a commercial dose, significantly reduced the populations of *B. tabaci* compared with cypermethrin in tomato.

From this study, we conclude that abamectin, acetamiprid, buprofezin, and bifenthrin can effectively manage immatures and adults of the whitefly *T. vaporariorum* infesting tomato in greenhouses. In addition, azadirachtin and mineral oil could be used in rotational manner to manage insecticide resistance problems that might develop in greenhouses. These materials also could be used in combination with biological controls in integrated pest management programs. The advantage of bio-pesticides, like azadirachtin, is that they perform better than conventional pesticides in an integrated approach and they have a short residual period. Narrow-range insecticides like abamectin, accetamiprid, and burpofezin could play an important role in reducing the overall reliance on broad-spectrum insecticides. Thus, this study has identified some promising insecticides and bio-pesticides for management of greenhouse whitefly under greenhouse conditions.

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