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Evaluation of different management strategies to control *Tuta absoluta* (Lepidoptera: gelechiidae) in tomato

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Abstract

Tomato leaf and fruit miner (*Tuta absoluta*) is a destructive pest of tomato and other Solanaceae plants in the world. The pest is problematic in open field and in greenhouses and can cause 80% to 100% yield loss if not properly managed. It was first reported in Sri Lanka during July 2017 on tomato in some poly-tunnels in Badulla District and later spread to many other areas in the country. As the pest is new to the country, no recommended insecticides or control measures were available at the time of initiation of this study. Therefore, experiments were carried out in poly-tunnels and in open fields for five consecutive seasons started from 2017 *Yala* to identify appropriate management strategies to control the larvae, and trapping methods to monitor and control of adults. Eleven insecticides were tested in poly-tunnels and four insecticides *viz*., Spinetoram 25% WG (2.5 g/10 L), Emamectin benzoate 5% SG (4 g/10 L), Indoxacarb 150 g L^{-1} EC (4 mL/10 L) and Abamectin 18 g L^{-1} EC (6 mL/10 L) were selected for further studies based on larval mortality recorded 24 hrs after application. Simultaneously, eight different traps including light, sticky, insecticidal and pheromonal were evaluated for mass trapping of *T. absoluta* adults in greenhouses. Results revealed that selected chemicals were effective in managing *T. absoluta* larvae in greenhouse tomato whereas only Spinetoram 25% WG (2.5 g/10 L) was effective for the same in the open field. The CFL light traps were suitable for mass trapping of *T. absoluta* adults in greenhouses. Pheromone traps can be used to monitor adult population.

Key words: Insecticides, Light traps, Pheromones, Tomato, *Tuta absoluta*

Introduction

Tomato leaf and fruit miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), is considered as a major pest of tomato (*Solanum lycopersicum* L.) and other Solanaceae plants in the world owing to its severity of attack and occurrence throughout the crop cycle (Shiberu and Getu, 2017). *Tuta absoluta* was originated in South/Central America and spreads into Europe, Middle East/Asia and Africa (Bala *et al*., 2019). The pest can cause 80% to 100% yield loss in open field and in poly-tunnels if not properly managed as it attacks leaves, flowers, stems and specially fruits in Solanceous crops (Illakwahhi and Srivastava, 2017 ; Shiberu and Getu, 2017). This pest was first reported in Sri Lanka in July 2017 in tomato cultivations carried out in poly-tunnel in the Keppetipola, Boralanda and Kolathenna areas in the Badulla district. Though some have claimed that *T. absoluta* was present in Sri Lanka since 2007 (personal communication, P.H. Ranaweera, Horticultural Crops Research and Development Institute, Gannoruwa), no documentary evidence is available as proof. After the first reporting of the incident, the pest has spread to other areas rapidly and threatened the tomato production and exportation. In 2018, just after one year of the reports of its first occurrence, the pest was found in open field tomato cultivations. The pest can spread to new cultivations through seedlings, infested vines, fruits, used containers and other farm equipments.

Tuta absoluta is a micro-lepidopteran moth and the adult is harmless. There are four larval stages, and larvae is a voracious feeder on tomato plants producing large galleries in leaves, damaging stalks, and consuming apical buds and immature and mature fruits. This is a challenging pest to control. The insect is often live in leaf mines and protected from contact of insecticides, thus rendering chemical control more difficult. *Tuta absoluta* is capable of rapid development of resistance to insecticides. Field populations of *T. absoluta* found in Latin American countries are known to be resistant to Avermectins, Milbemycins, Pyrethroids (group 6), Nereistoxin analogues (group 3A), Benzoylureas (group 14), Indoxacarb (group 15) and group 22A insecticides (IRAC, 2011). The pest has high reproduction capacity to produce 10 to 12 generations per year under favorable conditions (Illakwahhi & Srivastava, 2017). Therefore, integrated pest management (IPM) strategies including cultural, physical, biological and chemical methods are necessary to manage the pest. In Sri Lanka, no insecticides have been recommended to manage *T. absoluta* thus, farmers use various pesticides to manage this pest. Therefore, a series of studies was initiated to test the efficacy of potential insecticides against the larval stages of *T. absoluta* and other alternative management strategies such as light traps, sex pheromone traps, sticky traps and water pan traps for monitoring and mass trapping of adult moths.

Materials and Methods

Evaluation of insecticides against *T. absoluta* larvae in poly-tunnels

Three poly-tunnel experiments were conducted in the 2017 *Yala* season at Kolathenna in the 2017/18 *Maha* season at Mirahawwatte and the 2018/19 *Maha* season at Bindunuwewa in Sri Lanka to test the efficacy of insecticides to control *T. absoluta* larvae. These areas were selected based on higher pest damage recorded in the particular season. Tomato varieties "Alambra" was cultivated at Kolathenna and "Big beef" at Mirahawatta and Bindunuwewa during the study period. Tomato plants at their fruiting stage were naturally infested with *T. absoluta* during the experiments. During the three experiments, insecticides recommended by the Insecticide Resistant Action Committee (IRAC), 2011 for management of *T. absoluta* were used as treatments and water was used as the control. Spray concentrations were developed based on literature and the recommendations of the Department of Agriculture (Table 1). The experiment 1 was laid out at Kolatahena in a CRD with ten replicates. A single plant was considered as a replicate. Ten randomly selected tomato plants with one L2 larvae (≈ 4-5 mm) in a leaf per plant was selected, and tagged for each treatment. Insecticides were applied to both sides of the selected leaves using a hand sprayer. Larval mortality was recorded in 24 hrs for three days. Insecticides, which gave the highest mortality in this experiment were selected for subsequent studies.

The experiment 2 was conducted in Mirahawatte, Bandarawela during 2017/2018 *Maha* using four insecticides based on their efficacy based on the results of experiment 1 (Table 2) selected from previous study and experiment was laid out in a CRD with 20 replicates. Insecticides were applied to cover whole plant using a knapsack sprayer with a hollow cone nozzle and larval mortality was recorded in two days and seven days after insecticide application.

Table 1. Insecticides tested using tomato variety "Alambra' at Kolathenna in the 2017 *Yala* season at Kolatahena, Sri Lanka

Treatment	Volume/10 l of water	Chemical class	IRAC1 MOA2 group
T_1: Abamectin 18 g L^{-1} EC	6 mL	Avermectins, Milbemycins	6
T_2:Emamectin benzoate 5% SG	4 g		
T_3: Spinetoram 25% WG	2.5 g	Spinosyns	5
T_4: Spinosad 25 g L^{-1} SC	10 mL		
T_5: Lufenuron 50 g L^{-1} EC	10 mL	Benzoylureas	15
T_6: Novaluron 100 g L^{-1} EC	10 mL		
T_7: Indoxacarb 150 g L^{-1} EC	4 mL	Oxadiazines	22A
T_8: Chlorantraniliprole 200 g L^{-1} SC	1.9 mL	Diamides	28
T_9: Flubendiamide 20% WG	9.6 g		
T_{10}: Azadirachtin TS 1.0%	20 mL	Tetranortriterpenoid	UN
T_{11}: Azadirachtin F 5.0%	10 mL		
T_{12}: Untreated control (Water)	-	-	-

Table 2. Insecticides tested using tomato variety 'Big beef in the 2017/18 *Maha* season at Mirahawatte, Sri Lanka

Treatment	Volume/10 L of water
T_1: Abamectin 18 g L^{-1} EC	6 mL
T_2: Emamectin benzoate 5% SG	4 g
T_3: Spinetoram 25% WG	2.5 g
T_4: Indoxacarb 150 g L^{-1} EC	4 mL
T_5: Untreated control (Water)	-

The experiment 3 was laid out in CRD with 12 replicates at the in-service training institute (ISTI), Bindunuwewa using three promising insecticides (Table 3) during 2018/19 *Maha* using the same treatments as of experiment 2, except for the insecticide

Indoxacarb 150 g L^{-1} EC due to its unavailability (Table 3). Number of damaged fruits per plant, dead and live larvae per five leaves per plant was recorded before and weekly after spraying. Insect damage was assessed using a standard scoring system (Resende *et al*., 2005). Overall Plant Damage (OPD), Leaflet Lesion Type (LLT), and Percentage of Attacked Leaflets (PLA) were tracked over time and area under the curve of damage vs time was calculated. Smaller area under the curve is an indication of lesser damage to plants by the pest (Oliveira *et al*., 2012).

Table 3. Insecticides tested in the 2018/19 *Maha* season *Maha* at ISTI, Bindunuwewa and open field in Karagahawela, Sri Lanka

Treatment	Volume/10 L of water	Application interval	Chemical class	IRAC3 MOA4 group
T_1: Spinetoram 25% WG	2.5 g	7 days	Spinosyns	5
T_2: Emamectin benzoate 5% SG	4 g	7 days	Avermectins, Milbemycins	6
T_3: Abamectin 18 g L^{-1} EC	6 mL	7 days		
T_4: Untreated control (water)	-	-	-	

Following scoring systems were used to assess the damages

Overall Plant Damage (OPD)

– 0 = no leaf damage; 1 = 0.1 to 5% of total leaf area damaged, small, non-coalescent lesions; 2 = 5.1 to 20% of total leaf area damaged, small to medium-size, non-coalescent lesions; 3 = 20.1 to 50% of leaf area damaged, medium to large-size lesions; 4 = 50 to 80.1% of leaf area damaged, numerous, large, coalescent lesions; 5 = more than 80.1% of leaf area damaged, completely deformed plants

Leaflet Lesion Type (LLT)

– 0 = no lesion; 1 = small, rare lesions; 2 = small to medium-size lesions, rare, often towards the leaflet borders; 3 = medium to large-size lesions, coalescent; deformed leaflet borders; 4 = large-size lesions, coalescent; deformed leaflets; 5 = whole leaflet surface damaged

Percent of Attacked Leaflets (PLA)

– 0 = no leaflets attacked; 1 = 0.1 to 5% leaflets attacked; 2 = 5.1 to 20% leaflets attacked; 3 = 20.1 to 50% leaflets attacked; 4 = 50.1 to 80% leaflets attacked; 5 = more than 80% leaflets attacked

Unmoving larvae for a gentle stimulus by a LED light was considered as dead. Mortality data were corrected using (Abbott, 1925) formula.

Insecticide evaluation against *T. absoluta* larvae in open field tomato cultivation in Karagahawela and Bindunuwewa in the 2018/19 *Maha* season

Promising insecticides, except Indoxacarb 150 g L^{-1} EC, selected from the previous tests were used in the open field trial conducted in 2018/19 *Maha* season at Karagahawela, Bandarawela. Experiment was laid out in a RCBD with three replicates. Plot size was about 25 m^2. Planting and all cultural practices were done based on farmer's preference except insecticide application. Cultivation of Tomato variety "Padma", which was naturally infested with *T. absoluta* at the time of investigation. Insecticides were sprayed using Knap sack sprayer when an increasing trend in insect population was observed. Boarders were maintained to avoid cross contaminations. Data were collected from the middle plants avoiding boarders. Number of infested fruits and number of live and dead larvae of five randomly selected plants per treatment per replicate was assessed before and after treatment. Scoring system developed by Resende *et al*. (2005) was used for assessing the leaf damage.

Evaluation of different traps for mass trapping of *T. absoluta* adult moths in poly-tunnel

Eight trap designs (Table 4) selected from an observational study conducted at RARDC, Bandarawela, Sri Lanka were further evaluated in a farmer managed 279 square meter poly-tunnel at Kolathenna, Bandarawela during the 2017 *Yala* season. Two traps of each design was hanged at the canopy level of tomato plants (variety "Alambra") at 3 m distance and the number of *T. absolta* adults captured per trap was counted daily for eight days.

Table 4. Details of different traps installed for mass trapping of *T. absoluta* adult moth

Treatments
T_1: CFL light trap 8W
T_2: LED light trap 6W
T_3: Yellow sticky trap
T_4: Blue sticky trap
T_5: Red sticky trap
T_6: Gunny yarn dipped in 10% bee honey + Spinosad (0.4 mL/200 mL) trap
T_7: Gunny yarn dipped in 25% sugar solution + Spinosad (0.4 mL/200 mL) trap
T_8: Delta trap with pheromone lure (E,Z,Z) -3,8,11-Tetradecatrienyl acetate

Since light traps showed promising results, another study was conducted at Bindunuwewa to identify the best operating power of the light source. The Compact Florescence Lamp (CFL) bulbs with 7, 11, 15 and 23 W were tested following a similar procedure stated above. Number of *T. absoluta* adult moths captured per trap was recorded daily for two weeks.

Evaluation of Tutasan® water trap for *T. absoluta* moth trapping

The efficacy of Tutasan® water trap baited with a pheromone (Koppert Biological System) was assessed in a poly-tunnel condition at Mirahawatta and in open field conditions at Karagahawela to manage *T. absoluta* adult moths in tomato during 2018 season. Number of adult *T. absoluta* moths captured per trap was recorded daily for seven days.

Data Analysis

Data were analyzed after arcsine or square root transformation (Gomez and Gomez, 1984). Analysis of variance procedure used for data analysis and treatment means were compared using the Duncan's Multiple Range Test at p=0.05 using SAS software version 9.0.

Results and discussion

Effect of insecticides against larvae stage of *T. absoluta* in tomato in poly-tunnels

In the experiment 1, All insecticides tested were effectively controlled the larvae of *T. absoluta* in the poly-tunnel with the larval mortality recorded 24 hr after with Spinetoram 25% WG, Emamectin benzoate 5% SG, Indoxacarb 150 g L^{-1} EC and Abamectin 18 g L^{-1} EC performing better ($P<0.05$) than other tested insecticides (Table 5). Fourty eight hours after spraying T_1, T_2, T_3, T_4, T_6, T_7, T_8 and T_9 performed equally ($P>0.05$). However, Spinetoram 25% WG, Emamectin benzoate 5% SG, Indoxacarb 150 g L^{-1} EC and Abamectin 18 g L^{-1} EC were selected for further studies based on the fast and better performances recorded after 24 hrs of spraying.

Table 5. Mean percent mortalities of *T. absoluta* larvae population 24 and 48 hrs after exposure to various insecticides at poly-tunnel during the *Yala* season at Kolathenna, Sri Lanka

Treatments	Population before treatment	Mean percent cumulative mortality	
		after 24 hours	After 48 hours
T_1: Abamectin 18 g L^{-1} EC	10	70^{abc}	70^{abc}
T_2: Emamectin benzoate 5% SG	10	90^{ab}	100^{a}
T_3: Spinetoram 25% WG	10	100^{a}	100^{a}
T_4: Spinosad 25 g L^{-1} SC	10	60^{abcd}	70^{abc}
T_5: Lufenuron 50 g L^{-1} EC	10	30^{cde}	30^{dc}
T_6: Novaluron 100 g L^{-1} EC	10	60^{abcd}	70^{abc}
T_7: Indoxacarb 150 g L^{-1} EC	10	70^{abc}	90^{ab}
T_8: Chlorantraniliprole 200 g L^{-1} SC	10	30^{cde}	70^{abc}
T_9: Flubendiamide 20% WG	10	50^{bcd}	70^{abc}
T_{10}: Azadirachtin TS 1.0%	10	50^{bcd}	50^{bc}
T_{11}: Azadirachtin F 5.0%	10	20^{de}	40^{c}
T_{12}: Untreated control (water)	10	0^{e}	0^{d}
CV %		83.4	65.2

Means followed by the same letter are not significantly different by the DMRT at P=0.05.

As per the results of the experiment 2 conducted during the 2017/18 *Maha* season, the tested insecticides could be arranged in a descending order, considering the larval mortality and % leaf damage in leaf area as Spinetoram 25% > WG, Indoxacarb 150 g L^{-1} EC > Emamectin benzoate 5% SG > Abamectin 18 g L^{-1} EC (Table 6).

Table 6. Mean percent mortalities of *T. absoluta* larvae and damage area after exposure to four insecticides after 2 and 7 days at poly-tunnel in the 2017/18 in *Maha* season Mirihawatta, Sri Lanka

Treatments	*PBT	Mean percent corrected mortality		Damage area % of top 5 leaves per plant	
		2**DAS	7 DAS	2 DAS	7 DAS
T_1: Abamectin 18 g L^{-1} EC	20	20^{ab}	58^{b}	27^{b}	29.2^{b}
T_2: Emamectin benzoate 5% SG	20	30^{ab}	63^{b}	11.8^{bc}	11.8^{bc}
T_3: Spinetoram 25% WG	20	55^{a}	100^{a}	1.3^{c}	1.4^{c}
T_7: Indoxacarb 150 g L^{-1} EC	20	50^{a}	95^{a}	5.4^{c}	5.7^{c}
T_{12}: Untreated control	20	0^{b}	5^{c}	64^{a}	69^{a}
CV %		44.5	15.1	31.3	33.0

**PBT: Population before treatment, **DAS: days after spray*
Means followed by the same letter are not significantly different by the DMRT at P=005.

The insecticides Abamectin, Emamectin benzoate, Spinetoram, Spinosad, Novaluron, Indoxacarb, Flubendiamide and Azadirachtin TS. Wer effective against the larvae of *T. absoluta*, with the highest larval mortality been recorded for the treatment with Spinetoram 25% WG. This could be due to its both systemic and trans-laminar activity, which act fast on target pest. Similar results were reported by Hanafy and Sayed (2013) where Spinetoram has exhibited the highest toxic effect in reducing the infestation of *T. absoluta*, followed by Emamectin benzoate. Spinetoram 25% WG is registered in Sri Lanka against the Diamond Backed Moth (DBM) in cabbage due to its effectiveness on eggs, larvae and adults of lepidopteran insect pests. Therefore, further studies are needed to test the efficacy this insecticide on eggs and adult stage of *T. absoluta*. Gacemi and Guenaoui (2012) reported a 86.7% mortality of *T. absoluta* larvae when treated with Emamectin benzoate while results of the present study showed 90% mortality after 24 hrs of treatment. (Shiberu and Getu, 2017) reported that the active ingredient of Emamectin benzoate has a high potency against a broad spectrum of lepidopterous pests, however, also reported that Chlorantraniliprole 200 g L^{-1} SC showed 93.3% mortality after 24 hrs of exposure in the laboratory conditions. In contrary, results of the present experiment showed a low efficacy with Chlorantraniliprole 200 g L^{-1} SC (30%) on the larvae of *T. absoluta*.

Spinetoram 25% WG showed highest efficacy against *T. absoluta* larvae in the 2018/19 *Maha* season because only very few (0.3) live larvae were present on plants treated with the chemical (Table 7)

Table 7. Number of live larvae of *T. absoluta* on tomato plants treated with insecticides at different time intervals at poly-tunnel during the 2018/19 *Maha* season at ISTI, Bindunuwewa, Sri Lanka

Treatments	No. of live larvae					
	Before treatment	1^{st} WAA	2^{nd} WAA	3^{rd} WAA	4^{th} WAA	**TLLAT
T_1 - Spinetoram 25% WG	4.4(2.2)^a	0.0(0.7)^b	0.0(0.7)^b	0.1(0.7)^d	0.2(0.8)^d	0.3(0.9)^d
T_2 - Emamectin benzoate 5% SG	4.2(2.2)^a	0.0(0.7)^b	0.7(1.0)^b	4.6(2.0)^c	2.2(1.6)^c	7.6(2.7)^c
T_3 - Abamectin 18 g/L EC	2.8(1.8)^a	0.5(0.9)^b	1.0(1.1)^b	12.7(3.5)^b	10.2(3.2)^a	24.5(5.0)^b
T_4 - Untreated control	4.2(2.2)^a	1.9(1.5)^a	12.5(3.5)^a	37.9(6.1)^a	7.5(2.6)^b	59.8(7.7)^a
CV%	30.2	30.8	35.7	28.1	32.3	17.6

**WAA: Weeks after application, **TLLAT: Total live larvae after treatment*

Means followed by the same letter are not significantly different by the DMRT at P=005. Square-root transformed data are within parenthesis.

Plants treated with Spinetoram 25% WG and Emamectin benzoate 5% SG at the experiment conducted in poly-tunnel located of the ISTI, Bindunuwewa, showed significantly lower ($P<0.05$) levels of overall plant damage, leaflet lesion type and low percentage of leaflets attacked by *T. absoluta* compared to the untreated control and those treated with Abamectin 18 g L^{-1} EC. The number of damaged fruits per plant before and after insecticide application was not different ($P>0.05$) among treatments. However, after applying insecticides, the total number of damaged fruits recorded in four consecutive data collection dates at weekly intervals were significantly lower ($P<0.05$) in plants treated with Spinetoram 25% WG and Emamectin benzoate 5% SG (Table 8).

Table 8. Area under the damage curve and infested fruits in response to infestation by *T. absoluta* in the 2018/19 *Maha* season at ISTI, Bindunuwewa, Sri Lanka

Treatments	OPD	LLT	PLA	Number of damaged fruits per plant	
				*BT	*AT (4 harvests)
Spinetoram 25% WG	63.9^{c}	68.5^{c}	80.5^{b}	4.3(2.1)^{a}	0.2(0.8)^{b}
Emamectin benzoate 5% SG	81.1^{b}	74.7^{bc}	94.5^{ab}	3.9(1.9)^{a}	0.5(0.9)^{b}
Abamectin 18 g L^{-1} EC	85.5^{ab}	79.3^{b}	93.0^{ab}	3.7(1.9)^{a}	6.8(2.5)^{a}
Untreated control	96.2^{a}	96.8^{a}	105.6^{a}	2.8(1.7)^{a}	7.7(2.8)^{a}
CV%	18.7	12.3	19.7	29.2	15.8

**BT: before treatment* ***AT: After treatment*
Means followed by the same letter are not significantly different by the DMRT at P=005.
Square-root transformed data are mentioned within parenthesis.

The results of all experiments conducted at poly-tunnels revealed that Spinetoram 25% WG at the rate of 2.5 g L^{-1} 0l, Emamectin benzoate 5% SG at the rate of 4 g/10 L, Indoxacarb 150 g L^{-1} EC at the rate of 4 mL/10 L and Abamectin 18 g L^{-1} EC at the rate of 6 mL/10 L are effective in managing *T. absoluta* at the larvae stage. The pest is capable of developing resistance to insecticides rapidly (Illakwahhi & Srivastava, 2017). Hence, rotation of locally-registered effective insecticides according to the Mode of Action (MOA) window approach proposed by IRAC (2011) is proposed, namely, Spinetoram (MOA 5), Abamectin (MOA 6) or Emamectin benzoate (MOA 6) and Indoxacarb (MOA 22A). According to this approach, one insecticide can be applied for a 30 consecutive days (a window) based on the minimum duration of a single generation of *T. absoluta*. Multiple application of insecticides with the same MOA or different MOAs possible within a window. After first MOA window is completed, and if additional insecticides applications are required, different MOA's should be selected for use in the next 30 days. Insecticides with the same MOA group should not be re-applied for at least 60 days after a window closes.

Effect of insecticides against larvae of *T. absoluta* in tomato under open field

The results of the experiment conducted in open field showed that tomato plants treated with Spinetoram 25% WG had a significantly lower ($P<0.05$) levels of OPD, LLT and PLA by *T. absoluta* and total number of live larvae compared to untreated control, and plants treated with Emamectin benzoate 5% SG and Abamectin 18 g L^{-1} EC (Table 9). Sallam *et al*. (2015) have reported that Abamectin was a more effective insecticide than Chlorantraniliprole and Emamectin benzoate in managing *T. absoluta* in tomato grown under open field condition. However, the present study showed that Abamectin 18 g L^{-1} EC and Emamectin benzoate 5% SG showed better performance against larvae of *T. absoluta* in the poly-tunnels, however, only Spinetoram 25% WG showed good performances under open field conditions among the tested insecticides.

Table 9. The area under the damage curve in response to infestation by *T. absoluta* in tomato grown under open field during the 2018/19 *Maha* season

Treatments	OPD	LLT	PLA	Total live larvae
T_1: Spinetoram 25% WG	43.2^{c}	44.8^{c}	45.7^{c}	$0.3\ (1.0)^{c}$
T_2: Emamectin benzoate 5% SG	58.6^{b}	52.3^{bc}	63.7^{b}	$2.3\ (1.7)^{bc}$
T_3: Abamectin 18 g L^{-1} EC	69.1^{a}	57.6^{ab}	71.8^{ab}	$3.3\ (1.9)^{b}$
T_4: Untreated control	76.5^{a}	63.5^{a}	78.4^{a}	$7.7\ (2.9)^{a}$
CV%	6.8	8.9	6.4	15.5

Means followed by the same letter are not significantly different by the DMRT at P=0.05. Square-root transformed data are presented within parenthesis.

Evaluation of different traps against *T. absoluta* adult moths

The CFL light trap captured more *T. absoluta* adult moths (99.8 per trap per day) (Table 10) and was considered the most effective among tested traps for mass trapping of *T. absoluta* in tomato grown under poly-tunnel (Figure 1). Results also suggested that the CFL light traps are more effective (Figure 2) than LED light traps. In terms of operating power, the CFL light source with 8 W was similar that of 6 W in LED light source. During the study, number of adult moths captured in Delta trap together with pheromone lure was significantly lower ($P>0.05$) compared to that of the two light traps. The light traps are advantageous over pheromone traps as they attract both male and female moths (Sridhar and Kumaran, 2018). Further, Sridhar and Kumaran (2018) has reported that incandescent (yellow) 60 W bulb was more effective that white (bluish) bulbs in attracting *Tuta* moths.

Table 10. Mean daily captures of *T. absoluta* adults per trap in poly-tunnel during the 2017 *Yala* season in Kolathenna, Sri Lanka

Treatment	Average number of adult moths captured per day per trap form 1st to 8th August 2017								
	01	02	03	04	05	06	07	08	Average
T_1	150	390	305	225.5	371.5	155	0	0	99.8[a]
T_2	12.5	26.5	49	4	5	1.5	0	0	11.0[b]
T_3	1.5	0	0	0	0	0	0	0	0.0[e]
T_4	1.5	0	0	0	0	0	0	0	0.0[e]
T_5	1.5	0	0	0	0	0	0	0	0.0[e]
T_6	1	5.5	6	2	0.5	5.5	0	0	2.6[d]
T_7	1	7	4	6	7.5	8.5	4.5	2.5	2.5[d]
T_8	33.5	27	14	29.5	21	25.5	0.5	0	9.3[c]
CV%									4.6

Means followed by the same letter are not significantly different by the DMRT at P=0.05.


Figure 1. CFL light trap installed in tomato grown in poly-tunnel

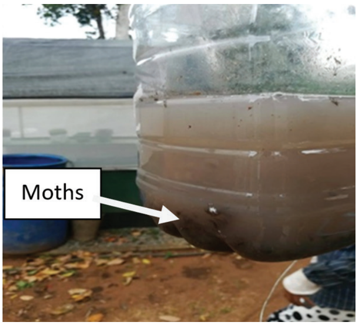

Figure 2. *T. absoluta* moths attracted to CFL light trap in poly-tunnel

During the 2017/18 *Maha* season, five CFL light traps with 8 W light source were evaluated in poly-tunnel located at Mirahawatta (357 m^2) and the mean number of adult moths captured per trap per day are shown in Table 11. Results revealed that there is a possibility to capture more than 1000 *T. absoluta* adult moths using CFL light traps with a light source of 8 W. Therefore, the results of the study carried out to identify the best suitable light source for CFL light trap are shown in Table 12. There was no significant difference ($P<0.05$) among CFL light traps with 7, 11 and 15 W light sources whereas significantly higher number of moths were captured in CFL light trap with 23W light source. Some authors (Sridhar and Kumaran, 2018) have suggested the need to study the peak activity of the pest as the light traps can also attract some of the natural enemies. Therefore, the timer based automated (switch on and off) light traps can be designed to minimize trapping of natural enemies (Sridhar and Kumaran, 2018). During the present study, the average number of non-target insects was recorded and they were mainly wasps and other insects belong to the order Hymenoptera. Results also revealed that there was no significant effect of light source on capture of non-target insects (Table 12).

Results revealed that Tutasan® water trap baited with a pheromone (Koppert Biological Systems) also effective in mass trapping of *T. absoluta* male mo7ths in tomato grown under open field (Table 13). However, to manage *T. absoluta* effectively, farmers should take necessary actions to prevent entry of pests to their cultivated fields. Monitoring of the pest can be done using light traps or pheromone traps. As pheromone traps are not yet locally available, farmers can easily use light traps for monitoring. Further, some of the other management options that could be included in a *T. absoluta* management programme include proper management of nursery with quality planting materials, field sanitation, use of clean tools, removal of infested plant parts and destruction of crop residues.

Table 11. Mean daily capture of *T. absoluta* adults per 8W CFL light trap in poly-tunnel during the *Maha* season at Mirahawatta, Sri Lanka

Average number of adult moths captured per day per trap form 16th October to 5th November 2017													
Day	16	17	18	21	22	23	27	30	31	1	3	4	5
Number	260	1110	350	1200	460	280	230	115	82	64	58	48	31

Table 12. **Mean daily captures of *T. absoluta* adults per light trap in poly-tunnel during the 2018/19 *Maha* season at ISTI, Bindunuwewa, Sri Lanka**

Treatment	Average number of adult moths captured per day per trap form 12th to 26th March 2019											
	12	**13**	**14**	**15**	**16**	**18**	**21**	**24**	**25**	**26**	**Average**	***ANTP**
T_1: $_{7}$ W	11(3)^{a}	58(8)^{b}	35(6)^{b}	29(5)^{a}	28(5)^{b}	20(4)^{a}	28(5)^{a}	16(4)^{a}	18(4)^{a}	4(2)^{b}	25(5)^{b}	6(2)^{a}
T_2: ^{11}W	17(4)^{a}	52(7)^{b}	47(7)^{b}	38(6)^{a}	37(6)^{b}	29(5)^{a}	37(6)^{a}	19(4)^{a}	23(4)^{a}	24(4)^{ab}	32(6)^{b}	7(3)^{a}
T_3: $_{15}$ W	18(4)^{a}	63(8)^{b}	54(7)^{ab}	37(6)^{a}	54(7)^{ab}	10(3)^{a}	16(4)^{a}	22(5)^{a}	38(6)^{a}	8(3)^{b}	32(6)^{b}	10(3)^{a}
T_4: $_{23}$W	4(6)^{a}	126(11)^{a}	111(10)^{a}	73(8)^{a}	85(9)^{a}	47(7)^{a}	48(7)^{a}	57(7)^{a}	52(7)^{a}	57(7)^{a}	70(8)^{a}	16(4)^{a}
CV%	22.9	7.3	14.1	22.2	9.6	23.0	24.2	27.3	32.6	23.2	4.4	44.1

**ANTP: Average number of non-target insects*

Means followed by the same letter are not significantly different by the DMRT at P=0.05%. Square-root transformed data are presented within parenthesis

Table 13. **Mean daily captures of *T. absoluta* male moths per Tutasan® water trap baited with a pheromone in tomato grown under poly-tunnel and open field during the 2018 *Yala* season**

Average number of adult moths captured per day per trap form 29th August to 05th September 2018							
Day	29	30	01	02	03	04	05
Open field	420	130	70	35	72	77	67
Poly-tunnel	10	5	24	12	8	Not tested	Not tested

Conclusion

The insecticides Spinetoram 25% WG (2.5 g L^{-1} 10), Emamectin benzoate 5% SG (4 g L^{-1} 10), Indoxacarb 150 g L^{-1} EC (4 mL/10 L) and Abamectin 18 g L^{-1} EC (6 mL/10 L) are effective in controlling *T. absoluta* larvae. As the pest can develop resistance against insecticides rapidly, a proper application schedule considering the MOA of insecticides is important. The recommended application schedule would be Spinetoram (MOA 5) followed by Abamectin (MOA 6) or Emamectin benzoate (MOA 6) and Indoxacarb (MOA 22A) for poly-tunnels whereas only Spinetoram 25% WG (2.5 g/10 L) is effective in the open field. The CFL light traps are suitable for mass trapping of *T. absoluta* adults in poly-tunnels. Delta trap together with pheromone lure and Tutasan® water trap baited with a pheromone is useful to monitor the pest population.

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