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Research Article

Evaluation of Selected Synthetic and Botanical Insecticides against *Tuta absoluta* (Lepidoptera: Gelechiidae) under Field Conditions

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Abstract: The invasive tomato leafminer *Tuta absoluta* has recently caused heavy losses to tomato growing areas around the world including Pakistan. Considering its significant damage potential, it is essential to conduct experiments using locally available botanicals and synthetic insecticides. Therefore, studies were conducted at a farmer's field in the district Shaheed Benazir Abad, Sindh, Pakistan during complete tomato season of 2023-24. Synthetic insecticides, i.e., Tracer 450SC ® (Spinosad 480 g/L), Belt 480 SC ® (Flubendiamide 480 g/L), Novastar 56EC ® (Bifenthrin 5%+ Abamectin 0.6%), Talstar 10EC ® (Bifenthrin), and Trigard 750 g/kg ® (Cyromazine) and botanical insecticides, i.e., Neem (*Azadirachta indica* A. Juss.), Tobacco (*Nicotiana tabacum* L.), Datura, (*Datura stramonium* L.), Peppermint (*Mentha piperita* L.), and Eucalyptus (*Eucalyptus camaldulensis* Dehn.), along with untreated control were evaluated against *T. absoluta* During both sprays, synthetic insecticides were found to be comparatively more effective than botanicals, with Flubendiamide and Spinosad being the two most effective insecticides. The effectiveness of all insecticides was comparatively better in the second spray than first spray. After one week of the two sprays, the maximum infestation reduction on tomato leaves and fruits was recorded with Flubendiamide (73.34% and 85.60%, respectively), followed by Spinosad (70.58% and 83.57%, respectively), whereas Eucalyptus and Datura were the least effective insecticides. Among botanicals, Neem resulted in a maximum corrected reduction in *T. absoluta* infestation on tomato leaves (52.33%) and fruits (55.20%). Due to the effectiveness of insecticides in reducing *T. absoluta* infestation, a significant effect on tomato fruit yield was also observed as maximum yield was recorded with Flubendiamide (433.40 ± 5.46 maunds per acre) and Spinosad (420.80 ± 3.20 maunds per acre) treatments, whereas neem (389.60 ± 4.86 maunds per acre) gave maximum yield among botanicals. Therefore, it is recommended that due to the better performance of Flubendiamide and Spinosad, they should be included in the integrated management of *T. absoluta* infestation in tomatoes, whereas Neem can also be used as botanical insecticide due to its effectiveness against it.

Keywords: Botanical insecticides, Infestation, Invasive, Management, Synthetic Insecticides, Tomato, *Tuta absoluta*.

1. INTRODUCTION

Tuta absoluta, commonly known as tomato leafminer, has been identified as one of the most destructive pests of tomatoes which can cause 80 to 100% yield losses when the conditions favor its growth and development [1-3]. Therefore, having such a huge damage potential, *T. absoluta* require early detection, monitoring, and control measures. Pheromone and various colored light traps, especially golden and blue, were found effective particularly in the monitoring of *T. absoluta*. Other

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studies also highlight the importance of pheromone and light traps in monitoring and mass destruction of *T. absoluta*, hence are included as key components in its integrated management [4-8].

Although various management tools are available for the control of *T. absoluta*, synthetic insecticides are still the most dependable and widely used approach to managing *T. absoluta* under field and greenhouse tomatoes [9]. However, it has been observed that most of the pesticides are unable to get desired control of *T. absoluta* because of its cryptic nature of damage [9-11] along with potential to develop resistance against most of the widely used insecticides [12-18]. Moreover, wide scale and frequent use of insecticides pose great threats to non-targeted organisms, humans, and the environment [19, 20]. Accordingly, it creates potential for the botanical and biorational pesticides to be used against *T. absoluta* because of their specific mode of action and less hazardous to non-target organisms and relatively safe to the environment [21].

Therefore, studies on the effectiveness of various botanicals against *T. absoluta* have been conducted in various countries which provided promising results to manage its various life stages [22-26]. Among botanicals, *A. indica* ethanolic extract and petroleum ether extract of *J. curcus* seeds were evaluated on eggs and larval stages of *T. absoluta* as both the extracts cause its significant mortality [23, 24, 27]. *Simmondsia chinsis* seed extracts applied at 100 percent concentration resulted in 75 percent mortality on 2nd instar larvae of *T. absoluta* [28]. It has also been observed that ethanolic leaf extract obtained from *P. amalago* resulted in 70% mortality of larvae and pupae within two-days exposure time, thus exhibiting acute toxicity at the concentration of 2,000 mg/L [29]. Moreover, the aqueous extracts of *M. azedarach, P. zonale, A. sativum, A. cepa, O. basilicum* also exhibited moderate to high mortality of different stages of *T. absoluta* [30]. Furthermore, crude extracts of three plants, i.e., *A. indica* seed, *C. citrates*, and *A. sativum* also resulted in 98, 97, and 95 % mortality of *T. absoluta* larvae, respectively within 7 days of the exposure in Ethiopia [25].

Recently, the presence of *T. absoluta* has been reported from tomato growing areas of Punjab, Khyber Pakhtunkhwa, and Sindh provinces of Pakistan [31-33], therefore, it has become imminent to conduct studies on its management using less toxic, new chemistry synthetic insecticides along with locally available botanicals against it. The results obtained could be helpful to determine the most effective synthetic and botanical insecticides that can be included in the integrated management of *T. absoluta* to restrict its losses and further spread in the country.

2. MATERIALS AND METHODS

The botanicals were obtained from the study areas, whereas synthetic insecticides were purchased from the authorized dealers. Two sprays were performed in the study as data were taken from ten randomly selected tomato plants per replications to count total and infested leaves and stems to calculate infestation percentage.

2.1. Study Location and Cultivation of Tomato

The study was conducted during the tomato growing season of 2023-24 at a farmer's field located in the district of Shaheed Benazir Abad, Sindh, Pakistan. Tomato variety Desi Local was cultivated at its recommended dose of 150 grams per acre. All the agronomic practices were applied as per the recommendations. The size of individual replication was maintained at 100 ft^2.

2.2. Treatments

The following synthetic and botanical insecticides were used in the study:

Tracer 450SC® (Spinosad 480 g/L), Corteva Agriscience @ 150 mililiter per acre
Belt 480 SC® (Flubendiamide 480 g/L), Bayer Crop Science @ 30 mililiter per acre
Novastar 56EC® (Bifenthrin 5%+ Abamectin 0.6%), FMC, Pakistan @ 500 mililiter per acre
Talstar 10EC® (Bifenthrin), FMC, Pakistan @ 400ml per acre
Trigard 750 g/kg® (Cyromazine), Syngenta Pakistan Ltd. @ 150 gram/acre
Neem, *Azadirachta indica* A. Juss.
Tobacco, *Nicotiana tabacum* L.
Datura, *Datura stramonium* L.
Peppermint, *Mentha piperita* L.
Eucalyptus, *Eucalyptus camaldulensis* Dehn.
Control (only water)

2.3. Preparation of Stock Solution of Botanical Pesticides

All the above-mentioned plant materials were collected afresh from the surroundings of the study area and brought in laboratory of Entomology Department, Sindh Agriculture University, Tando Jam, Pakistan. The procedure for preparation of botanicals was adopted from Kunbhar *et al*. [34] with slight modification. Five kilograms of each plant material was washed with distilled water and kept for air drying in the laboratory. Afterwards, plant materials were grinded using electric blender (GEEPAS China, Model GCG289) to get their small pieces and then boiled in ten litters of water for 30 minutes. The boiled material was then placed under shade for cooling and sieved from muslin cloth to get the fine stock solution for the spray. In the final stock solution, 125-gram detergent powder was added to avoid clotting of the planting materials and improve their dispersing quality. The calibration of water and individual botanical extract was done as per recommendation before their application.

2.4. Application of Insecticides, Experimental Design, Data Collection, and Analysis

Considering population development, the spray schedule against *T. absoluta* was designed as two sprays were applied during the study keeping in view the economic threshold levels i.e., 25-30% leaf or 10-12% fruit infestation. All the insecticides were applied as per their recommended doses (given in section 2.2). Experiment was arranged in a randomized complete block design with five replications maintained for the individual insecticide treatment.

Data on the infestation of *T. absoluta* on tomatoes was collected before the sprays, whereas subsequent observations were taken after 24, 48, 72, and 96 hours, and one week after the application of various insecticides. Moreover, ten randomly selected tomato plants per replication were observed to record *T. absoluta* infestation. *Tuta absoluta* infestation was assessed by counting the number of healthy and infested leaves and fruits by observing its characteristic damage symptoms, i.e., distinct 'blotch' mines with an accumulation of dark-colored frass in mines of leaves and holes in fruits.

The corrected reduction percentage in the *T. absoluta* infestations due to the application of various insecticides was calculated using Henderson and Tilton formula [35] given below:

$$Corrected\,\% = \left(1 - \frac{n\ in\ Co\ before\ treatment * n\ in\ T\ after\ treatment}{n\ in\ Co\ after\ treatment * n\ in\ T\ before\ tretment}\right) \times 100$$

n = number or infestation, Co = control, T = treatment

The Analysis of Variance along with the Least Significant Difference (LSD) test at 5% probability was used for the data analysis using STATISTIX 8.1 computer software.

3. RESULTS

3.1. Performance of Various Insecticides to Manage Infestation of *Tuta absoluta* on Tomato Leaves after First Spray

Figure 1 illustrates the results regarding the performance of the first spray of various botanical and synthetic insecticides on the infestation of *T. absoluta* on tomato leaves at various observation intervals. A non-significant ($F = 0.18$, $P = 0.9973$) difference was observed in the mean infestation of *T. absoluta* on tomato leaves of various treatment insecticides before spray as the infestation ranges between 28.21 ± 1.98 to 30.87 ± 2.63% among the treatments. Although an increasing trend in the infestation of *T. absoluta* on tomato leaves was recorded in the control, a reduction in its infestation was recorded in various insecticide treatments at various intervals of their application. Thus, after 24-hours after the application of insecticides, significantly ($F = 2.34$, $P = 0.0114$) the lowest infestation (21.03 ± 1.74%) on tomato leaves was recorded with Flubendiamide, followed by Spinosad (22.13 ± 1.84%) and Bifenthrin (24.90 ± 1.93%), whereas control showed the highest (31.23 ± 3.25%) infestation, followed by Eucalyptus (28.00 ± 1.75%) and Datura (27.70 ± 1.76%) treatments. Afterwards, a further decline in the infestation of *T. absoluta* was observed in insecticide treatments, but they exhibited significant differences in their effectiveness at various observation intervals i.e., 48-hours ($F = 3.45$, $P = 0.003$), 72-hours ($F = 4.79$, $P < 0.001$), 96-hours ($F = 5.63$, $P < 0.001$), and one week ($F = 9.25$, $P < 0.001$) of the insecticide application. Therefore, at the end of one week after the application of various treatments, the lowest

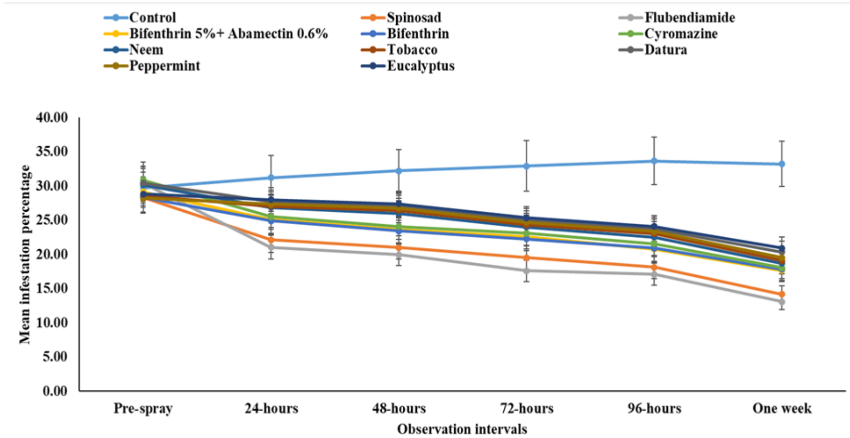

Fig. 1. Impact of various synthetic and botanical insecticides on the mean infestation percentage of *Tuta absoluta* on tomato leaves after the 1st spray.

infestation (13.07 ± 1.14%) of *T. absoluta* on tomato leaves was recorded with Flubendiamide, followed by 14.17 ± 1.27, 17.63 ± 1.60, and 17.80 ± 1.62% infestation recorded on Spinosad, Bifenthrin + Abamectin, and Bifenthrin insecticides. Among insecticide treatments, the highest (20.90 ± 1.62%) *T. absoluta* infestation on leaves was observed with Eucalyptus, followed by Datura (20.37 ± 1.57%) and Peppermint (19.50 ± 1.55%) treatments. Among botanicals, Neem (18.70 ± 1.56%) and Tobacco (19.10 ± 1.51%) were found comparable with some of the synthetic insecticides i.e., Cyromazine, Bifenthrin, and Bifenthrin + Abamectin in the reduction of *T. absoluta* infestation on tomato leaves. Overall, the highest *T. absoluta* infestation on tomato leaves was recorded in control at various observation intervals.

The corrected percent reduction in the mean infestation of *T. absoluta* on tomato leaves due to the first application of various insecticide treatments using Henderson and Tilton formula [35] is given in Figure 2. It was observed that at the end of one week after the application of various synthetic and botanical insecticides, none of the insecticide was capable of reducing 100% infestation of *T. absoluta* on tomato leaves. However, synthetic insecticides were comparatively more effective than botanicals with Flubendiamide and Spinosad being found to be the two significantly effective insecticides. Results also indicate that reduction in the *T. absoluta* infestation was observed after 24-hours of the application of various insecticide as maximum corrected infestation reduction (32.66%) was recorded with Flubendiamide, followed by Spinosad (29.14%) and Bifenthrin (20.285%). Among botanicals, the maximum infestation reduction was observed with Neem (13.98%) and Tobacco (13.45%). Overall, the minimum infestation reduction of *T. absoluta* was recorded

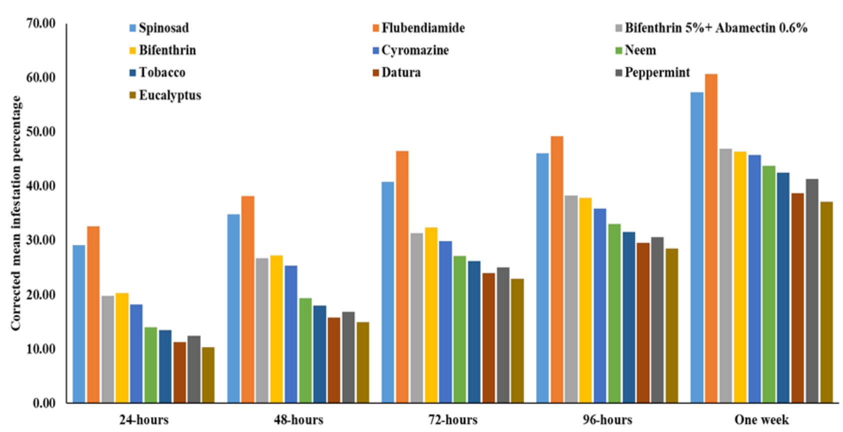

Fig. 2. Impact of various synthetic and botanical insecticides on the corrected mean infestation reduction percentage of *Tuta absoluta* on tomato leaves after 1st spray.

with Eucalyptus (10.35%) and Datura (11.31%). The corrected mean infestation of *T. absoluta* on tomato leaves in all the insecticide treatments showed a further decline till the end of one week of their application, especially in synthetic insecticides. Accordingly, the Flubendiamide (60.68%) and Spinosad (57.37%) insecticides were found most effective to reduce *T. absoluta* infestation on tomato leaves, whereas Eucalyptus (37.11%) and Datura (38.72%) were found the least effective to control the infestation of *T. absoluta.* Among botanicals, the performance of Neem (43.73%) and Tobacco (42.53%) was not significantly different from Bifenthrin + Abamectin (46.94%), Bifenthrin (46.44%), and Cyromazine (45.74%) to reduce *T. absoluta* infestation on tomato leaves.

3.2. Performance of Various Insecticides to Manage Infestation of *Tuta absoluta* on Tomato Leaves after Second Spray

Results regarding the impact of the second spray of various synthetic and botanical insecticides on the mean infestation of *T. absoluta* on tomato leaves at various time intervals are given in Figure 3. Comparatively lower level of *T. absoluta* infestation on tomato leaves was recorded in all the insecticide treatments, however, the application of various insecticides was found effective to significantly reduce the infestation, especially synthetic insecticides. The mean *T. absoluta* infestation in various treatments were not significantly (F = 0.03, P = 1.000) from each other, which ranged between 24.24 ± 2.44 to 25.60 ± 2.56%. After 24-hours of the application of various insecticides, a reduction was recorded in the mean infestation of *T. absoluta* on tomato leaves with the lowest infestation observed with Flubendiamide (16.60 ± 1.91%) and Spinosad (17.83 ± 2.23%), followed by Bifenthrin + Abamectin (18.37 ± 2.59%) and Bifenthrin (18.70 ± 2.10%). Among treatments, the maximum infestation (25.97 ± 2.31%) was recorded in control, followed by Eucalyptus (21.50 ± 1.99%), Datura (21.17 ± 2.01%), and Peppermint (20.37 ± 2.05%). Overall, a non-significant (F = 1.67, P = 0.0866) difference in the performance of different insecticides was recorded after 24-hours after their application to reduce *T. absoluta* infestation on tomato leaves. The effectiveness of various insecticides to reduce *T. absoluta* infestation on leaves was recorded till the end of one week of their application, however, a significant difference in their effectiveness was observed at various observation intervals i.e., 48-hours (F = 2.92, P = 0.0016), 72-hours (F = 5.62, P < 0.001), 96-hours (F = 7.72, P < 0.001), and one week (F = 15.32, P < 0.001). Thus, one week after the application of various insecticides against *T. absoluta,* significantly the lowest infestation (8.03 ± 1.09%) was recorded with Flubendiamide that was not significantly different from infestation observed with Spinosad (8.87 ± 1.21%). Among insecticide treatments, the highest *T. absoluta* infestation on leaves was recorded with Eucalyptus (13.97 ± 1.57%) and Datura (13.70 ± 1.59%), followed by Tobacco (13.43 ± 1.43%) and Peppermint (13.07 ± 1.35%), whereas Neem was found to be most effective botanical with lowest infestation (12.53 ± 1.43%) on tomato leaves. Overall, the highest *T. absoluta* infestation on tomato leaves was recorded in control at various observation intervals.

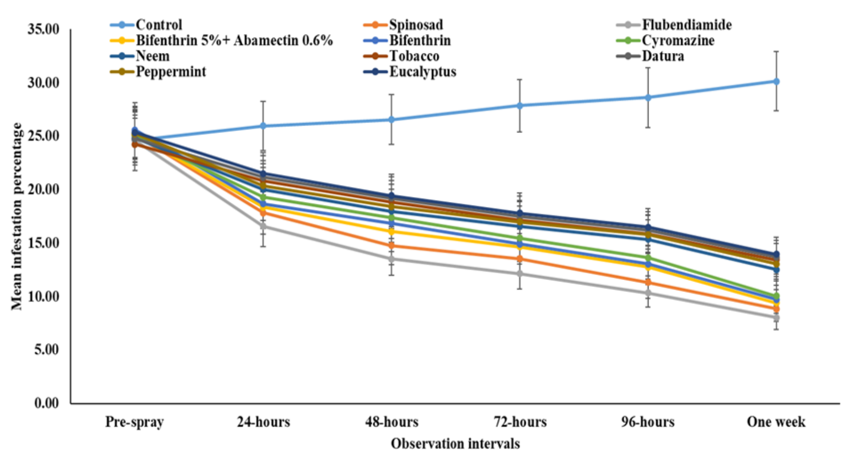

Fig. 3. Impact of various synthetic and botanical insecticides on the mean infestation percentage of *Tuta absoluta* on tomato leaves after 2^{nd} spray.

The corrected infestation reduction of *T. absoluta* on tomato leaves due to the application of various insecticides is given in Figure 4. Like 1st spray, Flubendiamide and Spinosad were found to be the most effective insecticides to reduce *T. absoluta* infestation on leaves, whereas among botanicals, Neem provided comparatively better performance to reduce the infestation. Moreover, a more comparative reduction in *T. absoluta* infestation on leaves was recorded during the 2nd spray of the various insecticide treatments than the 1st spray. The corrected infestation reduction of *T. absoluta* on leaves recorded with Flubendiamide after 24-hours of application was 36.07% that reached to 73.34% at the end of week, whereas the infestation reduction in Spinosad increased from 31.32% after 24-hours to 70.58% after one-week. Moreover, at the end of one week, the lowest infestation reduction was observed with Eucalyptus (53.65%), followed by Datura (54.54%), Tobacco (55.42%), Peppermint (56.64%), and Neem (58.41%). Among synthetic insecticides, Cyromazine was found to be the least effective with percentage reduction of *T. absoluta* infestation (66.59%) on tomato leaves, followed by Bifenthrin (67.70%) and Bifenthrin + Abamectin (68.81%).

3.3. Performance of Various Insecticides to Manage Infestation of *Tuta absoluta* on Tomato Fruits after First Spray

Figure 5 describes the results for the performance of the first spray of various synthetic and botanical insecticides on the mean infestation percentage of *T. absoluta* on tomato fruits. The pre-spray observations on *T. absoluta* infestation in various treatments exhibited a non-significant ($F = 0.09$, $P = 0.9999$) difference which ranged between 12.30 ± 1.39 to 13.40 ± 1.35% among the treatments. However, a significant ($F = 4.24$, $P < 0.001$)

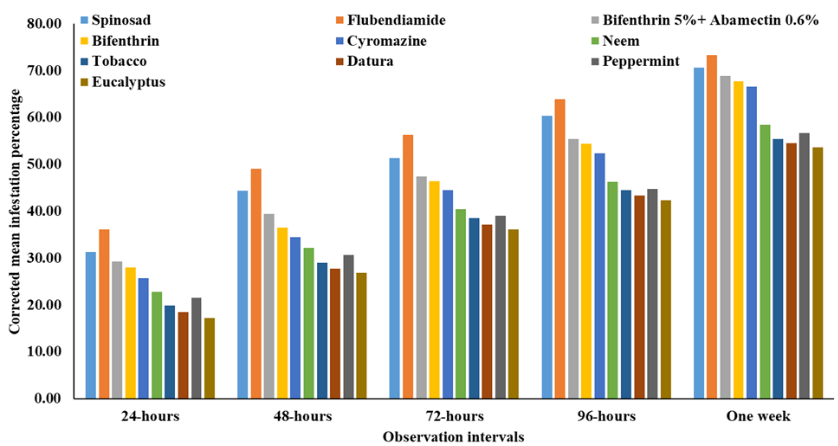

Fig. 4. Impact of various synthetic and botanical insecticides on the corrected mean infestation reduction percentage of *Tuta absoluta* on tomato leaves after the 2nd spray.

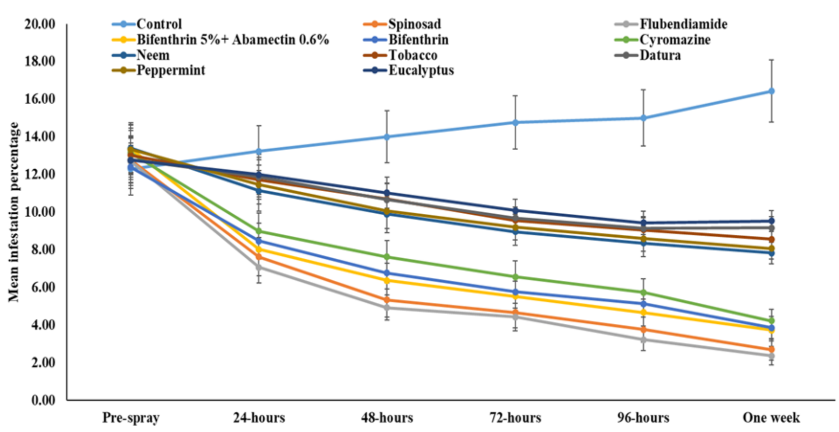

Fig. 5. Impact of various synthetic and botanical insecticides on the mean infestation percentage of *Tuta absoluta* on tomato fruits after 1st spray.

difference in the performance of various treatments was recorded after 24-hours of their application to reduce *T. absoluta* infestation on fruits. Flubendiamide (7.07 ± 0.84%) and Spinosad (7.63 ± 1.02%) were found to be the two most effective synthetic insecticides in infestation reduction of *T. absoluta* on fruits, followed by Bifenthrin + Abamectin (8.03 ± 1.00%), Bifenthrin (8.47 ± 0.94), and Cyromazine (9.00 ± 0.94%). Among botanical insecticides, Neem was found to be the most effective with the lowest infestation (11.13 ± 1.09%) of *T. absoluta* on tomato fruits, followed by Peppermint (11.47 ± 1.04%), whereas Eucalyptus (12.00 ± 1.07%) was recorded as the least effective among all the insecticides. The effectiveness of all the insecticides to reduce *T. absoluta* infestation on tomato fruits continued till the end of observations i.e., one week after their application but there was a significant difference among their performance at various observation intervals i.e., 48-hours ($F = 9.95$, $P < 0.001$), 72-hours ($F = 14.50$, $P < 0.001$), 96-hours ($F = 19.68$, $P < 0.001$), and one-week ($F = 32.23$, $P < 0.001$). At the end of week, the lowest *T. absoluta* infestation (2.37 ± 0.49%) was observed with Flubendiamide treatment, followed by Spinosad (2.70 ± 0.55%), whereas the infestation recorded in Bifenthrin + Abamectin (3.73 ± 0.57%), Bifenthrin (3.87 ± 0.59%), and Cyromazine (4.23 ± 0.61%) treatments was not-significantly different from each other. After one week, Neem was found to be the most effective botanical insecticide with mean *T. absoluta* infestation of 7.83 ± 0.56% on fruits, whereas Eucalyptus (9.53 ± 0.55%) and Datura (9.17 ± 0.59%) were found to be the least effective insecticides in infestation reduction on fruits. Overall, the highest *T. absoluta* infestation on tomato fruits was recorded in control at various observation intervals.

The corrected percentage reduction in *T. absoluta* on tomato fruits due to the first application of various synthetic and botanical insecticides is given in Figure 6. All the applied insecticides showed their effectiveness to reduce the *T. absoluta* infestation of tomato fruits but with significant differences as synthetic insecticides were found more effective than the botanicals. As per results, 24-hours after the application, Flubendiamide (46.60%) and Spinosad (42.32%) reduce the maximum infestation of *T. absoluta* followed by Bifenthrin + Abamectin (39.29%), Bifenthrin (36.02%), and Cyromazine (31.99%). The minimum infestation reduction percentage (9.32%) was recorded with Eucalyptus, followed by Datura (10.33%), whereas Neem (15.87%) was recorded as the most effective botanical to reduce *T. absoluta* infestation on fruits. Afterwards, a continuous reduction in *T. absoluta* infestation was observed in all the insecticide treatments at various time intervals i.e., 48-hours, 72-hours, 96-hours, and one week of their application. After one week, Flubendiamide (85.60%) and Spinosad (83.57%) emerged as the two most effective insecticides with respect to infestation reduction of *T. absoluta* on tomato fruits, whereas Eucalyptus (41.99%), Datura (44.22%), and Tobacco (47.87%) were found to be the least effective. Moreover, Bifenthrin + Abamectin (77.28%), Bifenthrin (76.47%), and Cyromazine (74.24%) was found to be equally effective in reduction of *T. absoluta* infestation on tomato fruits, whereas Neem (52.33%) was found to be most effective botanical, followed by Peppermint (50.91%).

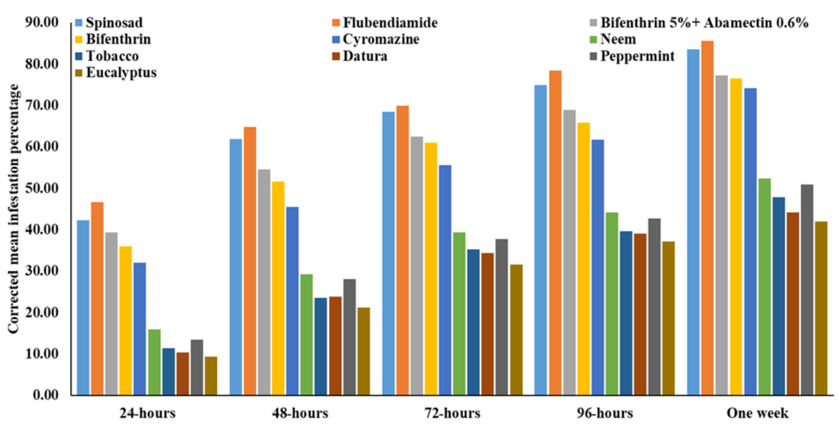

Fig. 6. Impact of various synthetic and botanical insecticides on the corrected mean infestation reduction percentage of *Tuta absoluta* on tomato fruits after 1st spray.

3.4. Performance of Various Insecticides to Manage Infestation of *Tuta absoluta* on Tomato Fruits after Second Spray

Figure 7 illustrates results for the effect of second spray of various insecticides on the infestation percentage of *T. absoluta* on tomato fruits. As compared to first spray, comparatively higher *T. absoluta* infestation (ranged between 13.40 ± 1.31% to 14.97 ± 1.49% among various treatments) was recorded on fruits with non-significant (F = 0.13, P = 0.9995) differences in the infestation among various insecticide treatments. However, 24-hours after application of various insecticides, there was a significant (F = 4.15, P < 0.001) difference in their effectiveness to reduce *T. absoluta* infestation on tomato fruits. Thus, Flubendiamide was found to be the most effective insecticide with the lowest *T. absoluta* infestation (7.13 ± 0.83%) on fruits, followed by Spinosad (7.97 ± 1.01%) and Bifenthrin + Abamectin (9.07 ± 0.92%), whereas Eucalyptus (12.03 ± 1.17%) and Datura (12.00 ± 1.03%) were found to be the least effective. Among botanical insecticides, Neem performed comparatively better with *T. absoluta* infestation on fruits of 11.57±1.09%, followed by Tobacco (11.83 ± 1.05%). The reduction in *T. absoluta* infestation on fruits due to the insecticide application was observed to continuously decline at various observation intervals up to one week. However, a significant difference in the performance of various insecticides was observed with respect to the level of infestation on fruits at various observation intervals i.e., 48-hours (F = 9.42, P < 0.001), 72-hours, 96-hours (F = 21.50, P < 0.001), and one week (F = 34.18, P < 0.001). Accordingly, after one week of the application of various synthetic and botanical insecticides, the lowest infestation percentage (2.00 ± 0.41%) of *T. absoluta* on tomato fruits was recorded with Flubendiamide, followed by Spinosad (3.00 ± 0.53%) and Bifenthrin + Abamectin (3.53 ± 0.57%), whereas Eucalyptus (10.17 ± 0.69%) and Datura (9.20 ± 0.68%) suffered the highest infestation. Among botanicals, Neem (7.47 ± 0.63%) was found to be the most effective, followed by Peppermint (8.30 ± 0.59%) and Tobacco (8.70 ± 0.54%). Overall, the highest *T. absoluta* infestation on tomato fruits was recorded in control at various observation intervals.

Figure 8 describes the results regarding the corrected infestation reduction of *T. absoluta* on tomato fruits after the second spray of various synthetic and botanical insecticides. The results indicated that all the synthetic insecticides were found significantly more effective to reduce *T. absoluta* infestation on fruits than the botanicals. A gradual increase in the infestation reduction of *T. absoluta* was observed since the application of insecticides that continued till the end of week. Accordingly, at the end of week, the highest corrected *T. absoluta* infestation reduction (88.00%) on fruits was recorded with Flubendiamide, whereas Spinosad and Bifenthrin + Abamectin caused 82.00 and 78.80% reduction in infestation, respectively. Among botanicals, Neem reduced 55.20% infestation of *T. absoluta* on tomato fruits, followed by Peppermint (50.20%). Overall, Eucalyptus and Datura were found to be the least effective among the evaluated insecticides against *T. absoluta* with corrected percentage reduction of 39.00 and 44.80%, respectively on tomato fruits.

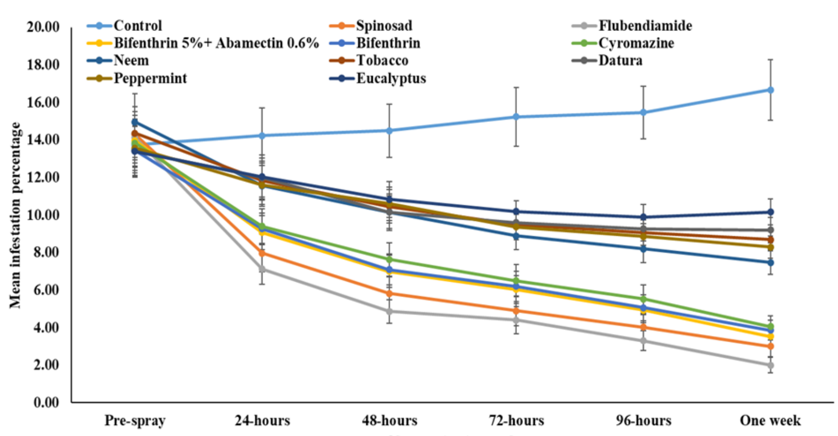

Fig. 7. Impact of various synthetic and botanical insecticides on the mean infestation percentage of *Tuta absoluta* on tomato fruits after the 2nd spray.

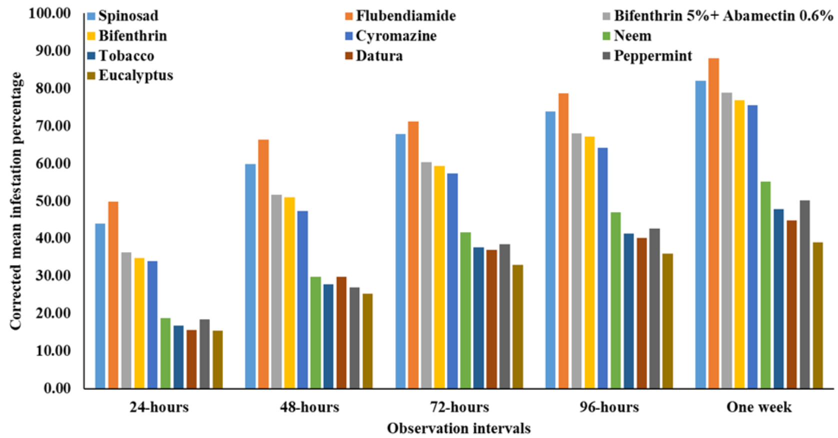

Fig. 8. Impact of synthetic and botanical insecticides on the corrected mean infestation reduction percentage of *Tuta absoluta* on tomato fruits after the 2nd spray.

3.5. Impact of Application of Various Insecticides on Tomato Yield in Response to Management of *Tuta absoluta* Infestation

The yield recorded in various insecticide treatments is given in Figure 9 which confirmed a highly significant ($F = 27.80$, $P < 0.001$) impact of *T. absoluta* infestation on tomato leaves and fruits on its yield. According to the results, the highest tomato yield was recorded in Flubendiamide (433.40 ± 5.46 maunds per acre) that was not significantly different from the yield obtained in Spinosad (420.80 ± 3.20 maunds per acre). Overall, the lowest yield (350.60 ± 5.89 maunds per acre) was recorded in control, followed by Eucalyptus (366.80 ± 4.21 maunds per acre). Moreover, tomato yields recorded in Bifenthrin + Abamectin (408.80 ± 5.33 maunds per acre), Bifenthrin (400.40 ± 3.83 maunds per acre), and Cyromazine (397.60 ± 4.71 maunds per acre) was not significantly different from each other. Among botanical insecticide treatments, the highest yield (389.60 ± 4.86 maunds per acre) was recorded in Neem, whereas yield recorded in Peppermint (380.20 ± 3.32 maunds per acre), Tobacco (375.20 ± 4.40 maunds per acre), and Datura (371.80 ± 5.37 maunds per acre) were not significantly different from each other.

4. DISCUSSION

The devastation caused by *T. absoluta* in various tomato-growing areas of the world necessitates effective measures to reduce its losses [36]. Accordingly, pesticides, both conventional and botanical, are widely used to keep *T. absoluta* populations below threshold levels, however repeated application of these pesticides is required [2, 37]. However, due to the ever increasing and injudicious use of synthetical chemicals against *T. absoluta* has resulted in the death of its natural

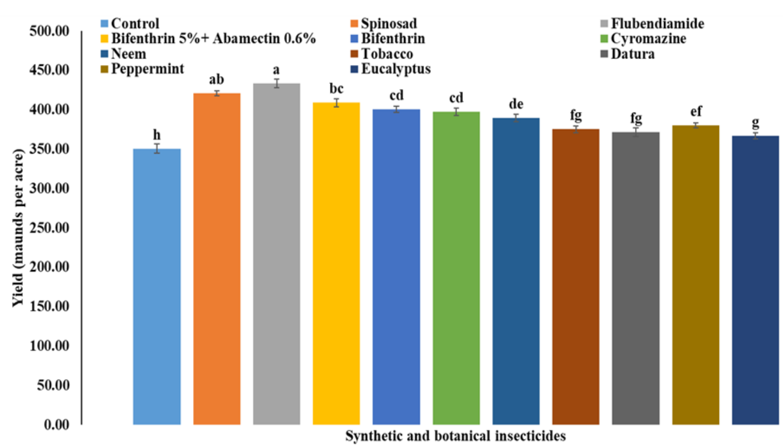

Fig. 9. Impact of synthetic and botanical insecticides used against *Tuta absoluta* on tomato fruit yield.
*Means followed with same letters are not significantly different (LSD = 13.331, $P < 0.05$).

enemies, development of resistant, environmental pollution, human health hazards, and residues in tomatoes which are mostly consumed fresh [38, 39]. Accordingly, there is an increasing trend in the use of biorational and botanical insecticides for the management of *T. absoluta* in field and greenhouse tomato orchards [40]. In continuity of the same, different synthetic and botanical insecticides evaluated in this study against *T. absoluta* were found effective in reducing its infestation on tomato leaves and fruits but differ significantly with respect to the level of control they provided against the pest. Synthetic insecticides i.e., Flubendiamide, Spinosad, Bifenthrin + Abamectin, Bifenthrin, and Cyromazine showed significantly better performance than botanical pesticides i.e., Neem, Tobacco, Datura, Peppermint, and Eucalyptus to reduce the infestation of *T. absoluta.* Both Flubendiamide and Spinosad were able to reduce *T. absoluta* infestation on leaves and fruits up to 73.34 and 88.00%, and 70.58 and 83.57%, respectively, whereas the remaining three synthetic insecticides were also capable to reduce more than 50% infestation of *T. absoluta* on tomato leaves and fruits. Overall, botanical pesticides were not so effective to reduce the infestation of *T. absoluta* in tomato, however, Neem and Peppermint were found to be comparatively more effective.

Considering synthetic insecticide as the most reliable method of managing *T. absoluta*, a lot of research has been done to evaluate various groups of insecticides to reduce their losses in tomato. In a field study, while evaluating eleven synthetic insecticides, significant performance of Spinetoram, Cyantraniliprole, Flubendiamide and Spinosad was observed to control *T. absoluta* infestation on tomato leaves and fruits [41]. In another study, comparatively higher toxicity of Spinosad against third instar *T. absoluta* larvae was recorded followed by Emamectin benzoate + Lufenuron and Flubendiamide, however, it was also highly toxic to *Trichogramma* sp. than Flubendiamide [42]. Another study of Kumar *et al.* [43] also recorded better performance of new chemistry insecticides i.e., Chlorantraniliprole, Spinosad, and Flubendiamide to control variable population of *T. absoluta* in Tamil Nadu, India. Moeini-Naghade *et al.* [44] while evaluating the efficacy of five different groups of pesticides i.e., Spinosad, Abamectin, Imidacloprid, Indoxacarb, and Cypermethrin against immature (eggs, larvae) and adults of *T. absoluta* found that none of the insecticides were found effective against the adult *T. absoluta* except Spinosad with 40% efficacy. However, Abamectin and Imidacloprid were the most and least effective insecticides against the targeted eggs. Moreover, Abamectin with 0.45 mg active ingredient (ai) per liter of LC_{50} was found to be the most effective against 3rd instar larvae, whereas Imidacloprid was found to be the least effective against the larvae. Hence, both Spinosad and Abamectin were recommended for their use to manage *T. absoluta* losses in the field.

Kandil *et al.* [36] studies under laboratory conditions found comparable performance of Spinosad along with Bt having Lepinox with synthetic insecticides (Chlorpyrifos and Indoxacarb) in causing significant mortalities among targeted 2nd instar *T. absoluta* larvae. The same studies also reported that the application of Bt formulation and Emamectin benzoate can increase the larval duration and cause pupal mortality, hence resulting in lower adult emergence, beside various abnormalities recorded in individuals of various life stages. The significant performance of Emamectin benzoate and Chlorantraniliprole to cause significant *T. absoluta* mortality was recorded under laboratory conditions, followed by Spinetoram and Abamectin Kandil et al. [45]. Moreover, under field trials, both Emamectin benzoate and Chlorantraniliprole also reduce 95.51 and 98.74% infestation of *T. absoluta* on tomatoes [46].

The findings of the above-mentioned studies mostly supported our findings as all the evaluated insecticides were effective in reducing the infestation of *T. absoluta*, especially Belt (Flubendiamide), Tracer (Spinosad) along with Novastar (Bifenthrin 5%+ Abamectin 0.6%). The higher efficiency of these insecticides against *T. absoluta* may be due to their novel mode of action (ryanodine receptor agonist, neuronal hyperexcitation and neurotoxic) and no or lower level of resistance among the targeted *T. absoluta* populations, as it has recently been introduced in Pakistan [31-33]. It has been mentioned that during 1990's, organophosphates and pyrethroids were frequently used for the management of *T. absoluta* in various countries of the world, but soon the pest developed resistance against most of these pesticides [15, 34], and the same led to the development and use of new chemical insecticides against it. Therefore, the results obtained in our study are supported by the findings of many studies where new chemical insecticides exhibited a significant impact on the infestation reduction of *T. absoluta*. In addition to the above studies, the higher efficacy of Flubendiamide, Emamectin benzoate, Chlorantraniliprole, and Spinosad against *T. absoluta* was observed by Roditakis *et al.* [46] as their LC_{50} values ranged between 0.03 to 0.53 ppm, whereas Chlorpyriphos and Cypermethrin were found to be the least effective with LC_{50} values between 475 to 2038 ppm. Similarly, Roby and Hussein [47] also recorded higher efficacy of Emamectin benzoate against *T. absoluta,* whereas more than 90% mortality of the pest was observed using Spinosad and Emamectin benzoate [48]. Moreover, while evaluating 11 insecticides against *T. absoluta*, Sridhar *et al.* [41] found Spinetoram, Cyantraniliprole, and Spinosad as the most effective insecticides.

In our study, only two sprays were required to reduce *T. absoluta* infestation to the acceptable threshold levels and the same may be attributed towards the new introduction or less intensity of the pest in the study area. However, generally frequent applications of insecticides are required to reduce the damage of *T. absoluta* [37] as studies suggested that up to 36 sprays in Brazil [49] were conducted to keeps its infestation below threshold levels, whereas 15 applications are reported from Spain [50]. Moreover, an alarming rise in the use of insecticides has been witnessed in Europe since the arrival of *T. absoluta* in the continent [51] which ultimately poses great threats to humans, the environment, and the non-target organisms [19].

Despite huge amounts of insecticides used against *T. absoluta,* mostly they failed to get desired results because of the endophytic nature of larvae to feed (feeding in the mesophyll of leaves), that make it difficult for chemicals to reach and kill the targeted larvae [52]. Moreover, it has also the ability to quickly develop resistance against most commonly used insecticides [14, 50] such as Cartap, Abamectin, and pyrethroids [12, 13], organophosphates, Spinosad, Emamectin Benzoate, Indoxacarb, Flubendiamide, Spinetoram, Cyantraniliprole, and Abamectin [36, 53], chloride channel activators, benzoylureas [54], and diamides [16, 17]. Accordingly, the insecticide resistant populations of *T. absoluta* have already been reported from Italy, Greece, and Israel [50]. Therefore, it is always suggested as a prudent practice that a rotation in the use of active ingredients should be practiced against any insect pests, including *T. absoluta* to reduce the chances of resistance development in the pest. In this way, the suggested rotation of active ingredients against *T. absoluta* for its better management include Imidacloprid, Indoxacarb, Spinosad, Deltamethrine (against adult moths) and Rynaxypyr [2]. In addition to rotation in the use of different insecticide groups against *T. absoluta*, the use of various botanical insecticides has also shown an increase during the 21st century keeping in view the health and environmental hazards of the synthetic insecticides [55].

Accordingly, in addition to synthetic insecticides, we also evaluated aqueous extracts of Neem, Tobacco, Peppermint, Datura, and Eucalyptus to determine their effectiveness in infestation reduction of *T. absoluta.* Although botanicals were not so effective as that of synthetic insecticides, Neem, Peppermint, and Tobacco aqueous extracts exhibited some promising results to reduce *T. absoluta* infestation on tomato leaves and fruits. Among botanicals, Neem and Peppermint were able to reduce up to 58.41 and 55.42% *T. absoluta* infestation on tomato leaves, whereas reduction in infestation on fruits was observed as 55.20 and 50.20%, respectively. The lower efficiency of botanicals observed in the study may be due to the fact that most of them have contact mode action resulting in antifeedant or repellency of the pests [56], whereas *T. absoluta* larvae possess cryptic nature of damage as it mostly remained concealed within tomato leaves and fruits, hence require insecticides with systematic mode of action to get its better management [57]. Despite lower performance of botanicals recorded in our study, promising results of various botanical and biorational insecticides, either commercial formulations or extracted in organic solvents, have been observed on mortality and infestation reduction of *T. absoluta* in tomatoes [40]. Among botanicals, Neem extracts or their commercial formulations have shown promising results on mortality and reduction of *T. absoluta* infestation in tomatoes [23, 58]. Kona *et al.* [23] recorded 24.5% and 86.70 to 100% mortality of the targeted *T. absoluta* eggs and larvae, respectively with the application of Neem extracts, whereas 25% and 87 to 100% mortality was recorded with Jatropha extracts within four days of the exposure. However, both extracts were unable to affect the viability of the treated eggs as all the remaining eggs hatched after four-days of exposure. Among other plants i.e., Basil, Garlic, Thyme, Castor Bean, Eucalyptus, Chinaberry, Onion, and Geranium also exhibited insecticidal potential against *T. absoluta* larvae, however their effectiveness varied significantly [59, 60].

Among other studies which identify the insecticidal potential of Neem and other botanical or biorational pesticides against *T. absoluta,* Buragohain *et al.* [40] reported that various Neem (Ecotin and EcoNeem) and *Bacillus thuringiensis* (Green Larvicide and Delfin) were found quite effective against the pest as their performance was comparable with that of commercial insecticide (Chlorantraniliprole). The findings of Jallow *et al.* [61] also supported our study results as 70-86% mortality of 2nd instar *T. absoluta* larvae was recorded under laboratory conditions when they were provided with leaves dipped with commercial Azadirachtin formulation at 3 grams per liter. Moreover, they also observed significant reduction in the *T. absoluta* infestation under field conditions with the use of Neem along with *Bt* and *Beauveria bassiana* commercial formulations. Similarly, Pires *et al.* [62] and Mollá *et al.* [63] also recorded significant impact of Neem and biorational insecticide on infestation reduction of *T. absoluta* on tomato. Comparatively higher efficiency of Neem extracts was recorded against *T. absoluta* under both laboratory and field conditions, followed by Garlic-Clove, Lemon, Bishkathali and Mahogany extracts, resulting in higher yields as compared to the control [64].

Although Neem or other botanicals have shown insecticidal potential against *T. absoluta*, there is a great variation in their effectiveness, particularly the home or field made formulations because of their inferior quality and standardization [2]. Moreover, Azadirachtin of the Neem extracts readily breaks down or isomerizes under sunlight due to its high photosensitivity, thus has low residue under field conditions and requires frequent application to manage insect pests including *T. absoluta* [58]. Another reason for the less adoptability of Neem-based commercial formulation is their cost that is estimated at US$ 12 to 15 per liter along with repeated application, hence making it difficult for small farmers to use [2].

In the study undertaken, the performance of botanical pesticides was significantly lower than the synthetics, and the same is in accordance with the findings of Hosseinzadeh and Aramideh [65], who reported that Thiocyclam and Spinosad were found to be more effective than Neem and Bt based insecticides against *T. absoluta* larvae. However, in a recent study, Taleh *et al.* [66] evaluated four commonly used insecticides i.e., Emamectin Benzoate, Imidacloprid, Lambda-Cyhalothrin, and Thiacloprid, along with biopesticide (Azadirachtin) against 2nd instar *T. absoluta* larvae using leaf-dipping methods to determine their effect on the survival and various growth parameters. The results indicated that Emamectin benzoate and Azadirachtin were found to be most effective in causing significant mortality and adversely affecting various growth parameters. Thus, pre-oviposition adult period, adult longevity and fecundity were significantly less in Emamectin benzoate treatment, whereas Emamectin benzoate and Azadirachtin also reduced the survivability of the 4th instar larvae.

5. CONCLUSIONS

All the synthetic insecticides were found to be more effective in reducing the infestation percentage of *T. absoluta* on tomato leaves and fruits, however there was a significant difference among them. Flubendiamide and Spinosad were the two best insecticides, whereas Bifenthrin + Abamectin, Bifenthrin, and Cyromazine were also able to reduce considerable reduction in *T. absoluta* infestation. Among botanicals, Neem and Peppermint were the two most effective botanicals. Therefore, considering infestation of *T. absoluta*, spray of Neem extracts should be done on a regular basis to keep its infestation under control. However, if required, application of synthetic insecticides, i.e., Flubendiamide or Spinosad should be used as the last option.

6. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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