Journal
of the
Plant Protection Society

Volume 5 **2018**

Plant Protection Society Nepal

Review Article

INTEGRATED MANAGEMENT OF SOUTH AMERICAN TOMATO LEAF MINER [*TUTA ABSOLUTA* (MEYRICK)]: A REVIEW

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ABSTRACT

Tuta absoluta (Meyrick) is one of the newly introduced insect pest of tomato in Nepal, which was first detected by Entomology Division, Nepal Agricultural Research Council from a commercial tomato grower of Balaju, Kathmandu on 16th May 2016. The pest occurs all-round the year within the temperature range of 20-27° C, and therefore, the environment of mid hills and plains of Nepal is suitable for sustaining the pest except during the winter season. *T. absoluta* pest mainly attacks Solanaceous crops, especially evident in tomato, however, it is also found in non-solanaceous crops. Larva of the pest is devastating causing damage in fruit, leaves and stem, and reducing tomato production by 80-100% in open field as well as in plastic house, if no control measures are carried out. Chemicals, like Spinosad, Chlorantraniliprole and Novaluron are recommended in Nepal for controlling this pest, but studies have revealed the inefficacy of chemical control measures due to wide host range, faster reproducing ability and development of pesticide resistance. Therefore, Integrated Pest Management (IPM) with mass trapping of the pest using pheromone trap, biological control by predator, parasitoid, entomopathogenic microbes, including cultural practices are imperative for the effective control of this pest.

Key word: Biology, chemical, efficacy, incidence, IPM, leaf miner, *Tuta absoluta*

INTRODUCTION

Tomato (*Lycopersicon esculentum* L.) belonging to the family Solanaceae is extensively cultivated as protective crop in the world. Due to the high commercial value, tomato has been an integral part of rural and modern farming system all round the world. It ranks the second in term of production after potato (Singh and Bhandari, 2015). The world's annual production of tomato is estimated to be 162 million tonnes generating a gross production value of more than US $63 billion (FAO, 2014). Similarly, in Nepal, the area under tomato is increasing every year by rate of 1.6% (MoAD, 2014/015; 2015/016).

Invasive insect South American tomato leaf miner, *Tuta absoluta* (Meyrick) [Lepidoptera : Gelichiidae], is a recently introduced pest of tomato in Nepal, which have been causing

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exponential decrease in tomato production. It has been causing 80-100% damage in open field and under plastic house grown tomato (Bajracharya *et al*. 2016). The aim of this review paper is to generate an attention towards the alternative technique of pest control that is easily available, environment friendly, sustainable and cost effective. Integrated Pest Management (IPM) practice which include mass trapping, biological control, cultural practices and others is preferred over chemical control (Muniappan, 2016; Zekeya *et al.*, 2017b).

METHODOLOGY

Necessary information were gleaned through various literature and reliable information on *T. absoluta* including the pest problem, pest origin/distribution, biology, field incidence and chemical control measures as well as Integrated Pest Management (IPM) techniques were collected. Relevant information were arranged systematically. Findings are summarized in the figures and briefed in texts with conclusive outline of the pest management.

RESULTS AND DISCUSSION

Origin and distribution of the pest

Origin place of *T. absoluta* is described by different authors. Illakwahhi and Srivastava (2017) reported that the pest was thought to originate from Chile. Zekeya *et al.* (2017a) reported that *T. absoluta* was recorded first in 1917 and as tomato pest in Peru in 1960s. Similarly, Ogur *et al.* (2014) revealed that *T. absoluta* was first described in 1917 in Peru and first recorded in 2006 in Spain. Since its origin, this pest widespread to South America, Europe then to South East Asia and Africa (Illakwahhi and Srivastava, 2017). In Nepal, *T. absoluta* was first identified by Entomology Division, Nepal Agricultural Research Council on 16th May 2016 (Bajracharya *et al.*, 2016). Since the initial year of introduction, this pest has caused extensive economic damage in the tomato field of Kavre, Bhaktapur and Lalitpur districts. Bajracharya *et al.* (2016) reported infestation from 14 locations among the 17 locations after field survey of Kathmandu, Bhaktapur, Lalitpur, Kavrepalanchowk, and Dhading districts. Extensive damage is attributed by the pest due to its wide host range, endophytic feeding habit and short life cycle.

Biology of the pest

The developmental period of pest varies according to environmental condition and temperature. Bajracharya *et al.* (2016) reported that the environment of mid hills and plains of Nepal are suitable for pest development except during the winter season. The average developmental period is 76.3 days at 14°C, 39.8 days at 19.7°C and 23.8 days at 27.1°C, respectively. The pest starts the infestation in warm temperature ranging between 24-27°C. This insect undergoes complete metamorphosis and completes its life cycle in a very short period of 24-28 days (PPD, 2017b). Adult moths are characterized by their silvery to grey scales (Berxolli and Shahini, 2017) and grey black spots on the fore wings (Retta and Berhe, 2015). They consist a pair of filiform antennae (Ballal *et al.*, 2016), having banded grey and dark brown color (Bajracharya *et al.,* 2016). Lifespan of adult female and male moths ranges between 10-15 days and 6-7 days, respectively (Desneux *et al.*, 2010). After copulation, adult female lays eggs alongside the rachis and underside of leaves. The eggs are small cylindrical, creamy white to yellow in color (Illakwahhi and Srivastava, 2017). Hatching occurs after 4-5 days and larvae of light green or yellow color emerge out (Godfrey *et al.*, 2016). Larvae undergo four larval instars and complete this phase in 14-16 days (PPD, 2017b). Then hatched larvae eventually turns greenish to light pink in the second to fourth instar (Retta and Berhe, 2015). Mature larvae are dark green in color and are distinguished by the characteristic dark band posterior to the head capsule (Ballal *et al.,* 2016). The larval period is most damaging and voracious, attacking all the above ground portion of the plant that includes leaves, stems and fruits (Tadele and Emana, 2017a). Larvae make large galleries in leaves, burrows in stalks, consumes apical buds and fruits (Berxolli and Shahini, 2017) and can thus cause loss up to 100% if control measures are not applied (Illakwahhi and Srivastava, 2017). Pupa lasts for 9-11 days in silken cocoon either in the soil or on the leaf surface, within mines or among plant debris (Ballal *et al.*, 2016).

Incidence of the pest

The *T. absoluta* is an oligophagous pest attacking several plant species. This pest mainly infests Solanaceous crops, like tomato, potato, eggplant, tobacco with high preference to tomato. Several authors have detected infestation of *T. absoluta* from plant of other families as well. A recent study evaluating the ability of *T. absoluta* to develop on 12 cultivated or non-cultivated plants of Solanaceae, Amaranthaceae, Convolvulaceae, Fabaceae, and Malvaceae species under laboratory condition shows that Solanaceae species are the most suitable hosts for *T. absoluta* and others could be opportunistically colonized with fewer incidences (Bawin *et al.*, 2015). Wide host range and narrow genetic base has led to rapid invasion of the insect pest. Lack of strong quarantine regulations, poor enforcement of available act/regulations and lack of screening at the borders are the other factors contributing behind the rapid invasion of the pest (Illakwahhi and Srivastava, 2017). Use of heavy chemical pesticide like Organophosphates, Abamectin, Pyrethroid, Cartap makes the insect resistant to them. Therefore, new formulation of chemical pesticide, like Indoxacarb, Chlorfenapyr, Spinosyns, Diamides being used in Brazil (Campos *et al.,* 2014). Zekeya *et al*. (2017b) reported that chemical control of *T. absoluta* is quiet uneconomical and unsustainable, arising problems like environment pollution and causing harm to beneficial insects. Similarly, Retta and Berhe (2015) dictated that the chemical method is gradually being inefficient due to the development of insecticide resistance by *T. absoluta*.

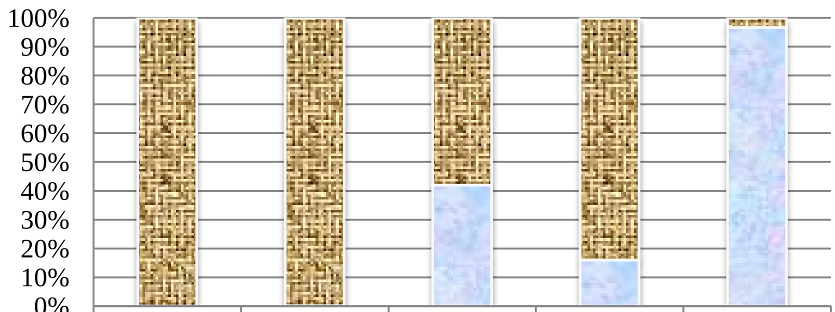
The field survey of Bajracharya *et al.* (2016) revealed 76-100% damage in Karita variety of tomato in Kavrepalanchowk district of Nepal. Similarly, damage of 51-75% was recorded in Samjhana and Srijana variety in Kathamandu and Bhaktapur district, respectively. Control of pest is considered as a huge challenge because of the high reproduction capacity, and wide host range of the pest (Birgucu *et al.*, 2014). Use of chemical pesticides has been an indispensible tool now-a-days, however, with respect to its negative effect in the environment, it is aimed to reduce pesticide and its adverse effects. Researchers have been seeking the best management practices which lower the population of *T. absoluta* below economic injury level along with environment sustainability. Considering the ability of pest to develop resistance to pesticide, negative effect of pesticide over environment and beneficial insects and residual problem of pesticide, alternative pest control method like Integrated Pest Management (IPM) are highly recommended as controlling measure (Illakwahhi and Srivastava, 2017).

Pesticide use and problems

In order to minimize the infestation of pest, different chemicals have been used in different part of world. In Egypt, synthetic chemical pesticides like Organophosphates and Pyrethroids have been used during 1970's and abamectin, Spinosad, Tebufonzide and Chlorfenpyr have been introduced in 1990's (Abdelgaleil *et al.*, 2015)**.** In Africa, common chemicals used against *T. absoluta* are Pyrethroids, Organophosphates, Spinosad, Emamectin benzoate and Abamectin (Zekeya *et al.*, 2017a). Chemicals, like Spinosad (Trade name : Tracer), Chlorantraniliprole (Trade name : Coragen, Alcora) and Novaluron (Trade Name : Remon, Pedestal, Remo 10) are recommended by Plant Protection Directorate in Nepal @ 1 ml per 3 liter of water, 3 ml per 10 liter of water and 1 ml per liter of water respectively (PPD, 2017b).

Since the origin of *T. absoluta*, several chemicals have been used haphazardly for its control. Braham and Hajji (2012) reported that *T. absoluta* developed resistance against pesticides, like Abamectin, Cartap, Methamidophos and Permethrin in Brazil and against Deltamethrin and Abamectin in Argentina. In the same way, Campos *et al.* (2014) described that after the introduction of *T. absoluta* in Brazil, there was dramatic increase in the use of chemical pesticide during early 1980's. Heavy use of chemical insecticide for control of *T. absoluta* lead to the development pesticide resistance against pesticides, like Organophosphates, Pyrethriods, Abamectin and Cartap within a decade, i.e. during 1990's and early 2000. This resistance led to subsequent use and registration of new insecticide, like Indoxacarb, Chlorfenapyr, Spinosyns, and Diamides. The trend of pesticide resistance development and registration of new pesticide, as an alternative to control the pest has been evident all over the world. Frequent application of pesticide has been reported by Zekeya *et al.* (2017a). The authors reported 15 applications of pesticide in Spain and up to 30 applications in Brazil. Similarly, more than 18 chemicals were introduced during 2009-2011 in Tunisia for the control of tomato borer but none of them were efficient. Ponti *et al.* (2012) revealed that the pest has been showing high potential for pesticide resistance because of their narrow genetic base and the high frequency of mutation associated with Pyrethroid that caused resistance of pest against Pyrethroid. The authors further indicated that insecticide resistance facilitated the rapid expansion of the pest invasive range.

Continuous application of chemical insecticide has multiple side effects, which ranges from pesticide resistance development to pesticide residue in food crops. An experiment conducted in Brazil to determine the rate of development of insecticide resistance comparing relative toxicity of insecticide to the parental Spinosad resistant strain and its derived strain after 15 generation of selection for Spinosad resistance showed that there was steady increase of the level of Spinosad resistance until the 7th generation of selection, reaching to 5000 fold increase in the level of resistance (Figure 1). Also, the experiment showed high heritability of Spinosad resistance, representing a 10 fold increase in the level of resistance at each 1.88 generation (Campos *et al.*, 2014). The decrease in toxicity of insecticide indicates for the use of relatively high quantity of insecticide in subsequent generation. Similarly, the potential pattern of cross resistance was also evaluated by authors, which showed increased resistance against insecticide, like Indoxacarb, Abamectin, Chloefenapyr and others, however, the case was reverse for Chlorantraniliprole.



	Spinosad	Spinetoram	Indoxacarb	Abamectin	Chlorantraniliprole
LC50 after 15 generation	1717.3	195.94	1.19	2.85	0.42
LC50 of parental strain	0.41	0.29	0.86	0.54	12.18

Fig. 1 : Relative toxicity of insecticides to the parental Spinosad- resistant strain and its derived strain after 15-generations of selection for Spinosad resistance (Campos *et al*., 2014)

Similarly, a study carried out in open field condition to determine the dissipation rate of four different insecticide in tomato fruit showed that the amount of insecticide residues found in the fruit varied with different day interval after application (Figure 2). Spinosad and Abamectin residues were undetectable after 7 days of treatment. However, 92.4% and 95.4% Chlorpyrifos and Thiamethoxam were found to be dissipated respectively after 15 days of treatment. Based on the Maximum Residue Level (MRL) values, the pre-harvest intervals (PHIs) were 15, 10, 7, and <1 days for Chlorpyrifos, Thiamethoxam, Abamectin, and Spinosad, respectively (Ramadan *et al.*, 2015). The study indicates that there is longer waiting period for insecticide with synthetic formulation than those of biological origin (Figure 2). This indicates that if synthetic insecticide is applied than there is less possibility to catch the early market demand of tomatoes.

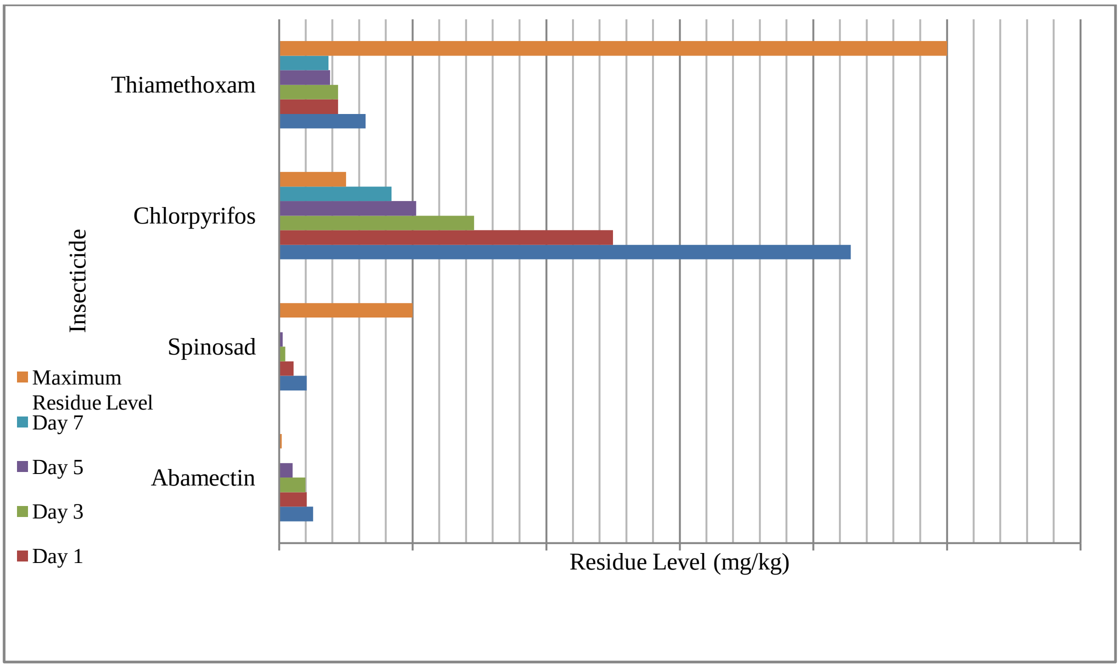


Fig. 2 : Insecticide residues detected in tomato fruit samples under open field condition (Ramadan et al., 2015)

A study in Turkey by Birgucu *et al.* (2014) on growth inhibitory effects of bio- and synthetic insecticides: Azadirachtin, *Bacillus thuringiensis* Berliner, *B. thuringiensis* + Azadirachtin, Chlorantraniliprole + Abamectin, Metaflumizone, Emamectin benzoate and Spinosad, on the third instar larva of *T. absoluta* shows similar performance, However, Hanafy and El-Sayed (2013) reported that the insecticide of biological origin (like : Spinetoram, Spinosad and Emamectin) were more effective than the chemical insecticides- Pyridalyl, Indoxcarb, Coragen and Chlorfenapyr under field condition. Similarly, a study carried out to determine the short and long term effects of *B. thuringiensis* var *kurstaki* (Btk), Azadirachtin (AZ), a mixture of AZ + Btk, and Indoxacarb in open field condition showed that the mixture of AZ + Btk gave the highest long term effects on the pest and damage reduction and gave 100% reduction in fruit and foliage damage as compared to the Indoxacarb (Figure 3) (Nazarpour *et al.*, 2016).

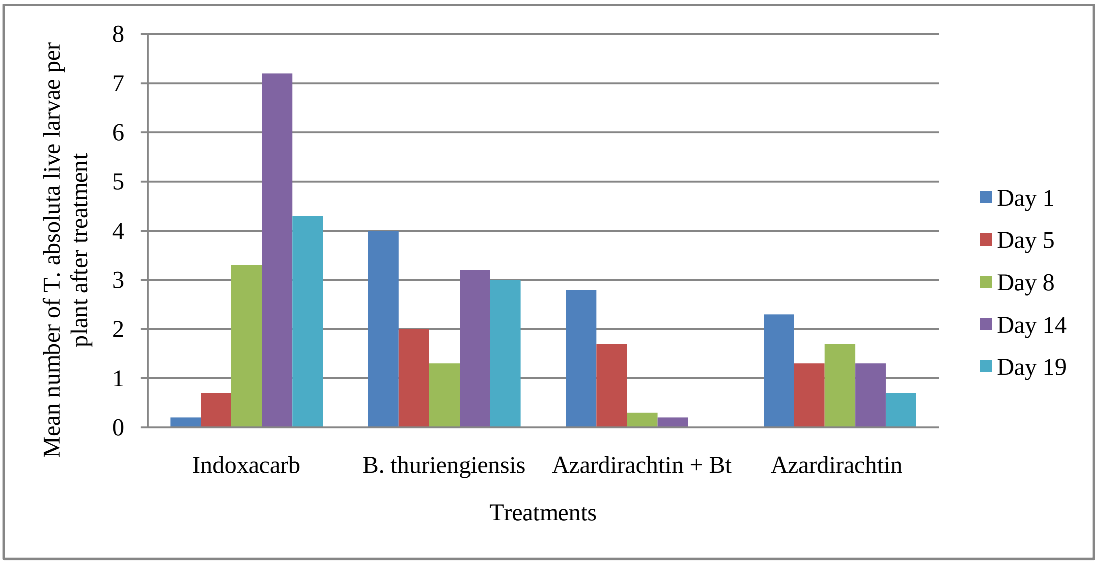


Fig. 3 : Comparing short and long term effects of chemical and bio-pesticides (Nazarpour *et al.*, 2016)

To minimize the side effect of chemical insecticide, Plant Protection Directorate (PPD), Nepal recommends judicious use of pesticides with different active substances and different mode of action. Also, it suggests to avoid the overuse of pesticide to reduce the ability of pest to develop resistance against pesticide (PPD, 2017a). Control of *T. absoluta* using chemical pesticides is found extremely difficult and quite challenging (Illakwahhi and Srivastava, 2017). Therefore, it is essential to focus toward an environmentally sound and ecologically sustainable measures like Integrated Pest Management (IPM).

Integrated pest management (IPM)

IPM comprises biological control, habitat manipulation, modification of cultural practices, physical and mechanical modification, judicious use of chemicals and other method of control. Mass trapping using pheromone lure, use of entomopathogenic agent, entophagous agents, like predators and parasitoids and bioinsecticide are some of the tactics that are considered the best option for the management of *T. absoluta* (Illakwahhi and Srivastava, 2017; Sah, 2017; Muniappan, 2016). Hence, for effective management of *T. absoluta* following practices are imperative.

Cultural practices

It includes crop rotation, inter cropping, trap cropping and others, in which environmental condition are altered so that pest attack crop of less economic importance. *T. absoluta* prefers tomato, but is also found to feed, develop and reproduce on other cultivated Solanaceae such as egg plant (*Solanum melongena* L.), potato (*Solanum tuberosum* L.), sweet pepper (*Solanum muricatum* L.) and tobacco (*Nicotiana tabacum* L.) as well as on non-cultivated Solanaceae (*Solanum nigrum* L., *Solanum eleagnifolium* L., *Solanum bonariense* L., *Solanum sisymbriifolium* Lam., *Solanum saponaceum* L., *Lycopersicum puberulum* Ph. etc.) and other naturally available host-plants such as *Datura ferox* L., *Dhatura stramonium* L. and *Nicotiana glauca* Graham (Desneux *et al*., 2010; Mohamed *et al*., 2015). Therefore, crop rotation with non-solanaceous species can reduces the impact of *T. absoluta*. Intercropping tomato with coriander (*Coriadrum sativum* L., Apiaceae) and gallant soldier (*Galinsoga parviflora* L., Asteraceae) shows positive effect on reducing pest density and enhancing natural enemies. Similarly, the authors also reported that tomato plants potted in soil from organic farming systems had half the number of *T. absoluta* eggs when compared to tomato plants grown in soil from conventional systems (Ponti *et al.*, 2012).

Physical method

Main source of pest invasion is the infested seedling. Therefore, use of healthy seedling is very important for gaining a wealthy stock. Protecting the tomato seedling in nursery bed by net house of 1.6 mm mesh size is effective for reducing the infestation of pest during seedling (PPD, 2017b). The greenhouse or net house must be sealed properly and screened at vents in the roof and sides. The disciplined use of double entry doors can reduce migration of pests into the greenhouse (Retta and Berhe, 2015). While using net house or green house, special consideration should be made for ventilation. Similarly, collection and destruction of damaged plant part should be performed on regular basis.

Use of pheromone traps

Pheromone traps are used as the first line of defense so as to determine the presence and abundance of insect pests, which in turn, helps to determine the correct timing for insecticide applications leading to a rational use of pesticides (Berxolli and Shahini, 2017). Usually, pheromone trap involves two main ways of insect pest control- mass annihilation and mating disruption (Gebremariam, 2015). For mass annihilation, pheromone lures are coupled with sticky trap, water trap, Wota T-trap and others. In this technique, special attention are given to the color of traps which influence the movement of insect towards it. An experiment showed that red sticky trap with 39.7% reflectance at 612.1 nm dominant wavelength trapped the greatest number of moths while the yellow sticky trap captured the least (Taha *et al.*, 2012). A research conducted in Tunisia by Braham *et al.* (2013) revealed greater efficacy of mass trapping over chemical control. For mating disruption, a sexual attractant similar to the one secreted by female moth has been invented artificially using (3E, 8Z, 11Z), 3,8,11-tetradecatrienyl acetate as major and (3E,8Z) tetradecadien-1-yl acetate as minor component (Illakwahhi and Srivastava, 2017).

(PPD, 2017a) recommend to use 1 trap per ropani in Nepal. However, the ability of female *T. absoluta* to reproduce parthenogenetically has weakened the use of such pheromone-based controls (Illakwahhi and Srivastava, 2017).

Use of Plant based pesticides

Plant based pesticides are better over synthetic chemical pesticides as they are environment friendly, biodegradable, easily available, ecologically sound and sustainable. Active metabolites present in plants act as toxicant for pest. Gebremariam (2015) reported insecticidal property of botanical extract of Neem (*Azadirachta indica* A. zuss.) and Jatropha (*Jatropha curcus* L.), against eggs and larvae of tomato leaf miner causing 25% and 18% of egg mortalities four days after treatment and 33- 46.7% and 23.5 - 48.5% larval mortalities within 24 hours of treatment. Similarly, Brito *et al*. (2015) reported *Piper mikanianum* L. and Moreno *et al*. (2012) reported compounds of *Acmella oleracea* L. to have insecticidal property for controlling of *T. absoluta.* An experiment in Tunisia shows a similar effect of botanical extracts of Neem oil + Azadiractin named “Bioticide” and biological insecticide “Thuricide” based on *B. thuringiensis* var. *kurstaki* (Btk). Such botanical extracts along with mass trapping reduced the damage of *T. absoluta* significantly (Harbi *et al.*, 2013). The experiment in Ethiopia evaluated *Azadirachta indica*, *Nicotiana* spp., *A. sativum* and *Cymbopogon citratus* showing potential effect on the larvae of *T. absoluta* at 10% concentration after a week of application (Tadele and Emana, 2017c).

Use of entomo-pathogenic microbes

Use of microorganisms, like bacteria, fungi and nematode as biopesticides for the management of *T. absoluta* has become imperative (Tadele and Emana, 2017b). Microbes attack the pest by their pathogenic effect leading death of the pest.

Zekeya *et al.* (2017a) reported *Metarhizium anisopliae* (fungus) and *Bacillus subtilis* (bacteria) as the successful formulation to reduce the population of *T. absoluta* on tomato in America and Europe. *M. anisopliae* and *Beauveria bassiana* have also been reported as an effective formulation. In a laboratory study of Algeria, fungi *Aspergillus flavus* and *M. anisopliae* caused 42% and 56% mortality of adult and pupae, respectively (Lakhdari *et al*., 2013). A preliminary study making biological tests on the third stage larvae of *T. absoluta* using bacterial strain of *Bacillus brevis* I13 (GQ397858) and two local strains of *B. bassiana* (P1 and P2) showed 90-100% control of the pest (Ameni *et al.*, 2013). Figure 4 showed that a study conducted under open field condition revealed that *B. bassiana* and *M. anisopliae* at 2.5×10^9 conidial/ml gave similar mortality of *T. absoluta* as that of Chlorantraniliprole. Similarly, under glasshouse condition, maximum mortality occurred at 2.5×10^9 conidial/ml of *B. bassiana* (84.04%) followed by *M. anisopliae* (76.31%) on 10^{th} day of the treatment (Tadele and Emana, 2017b).

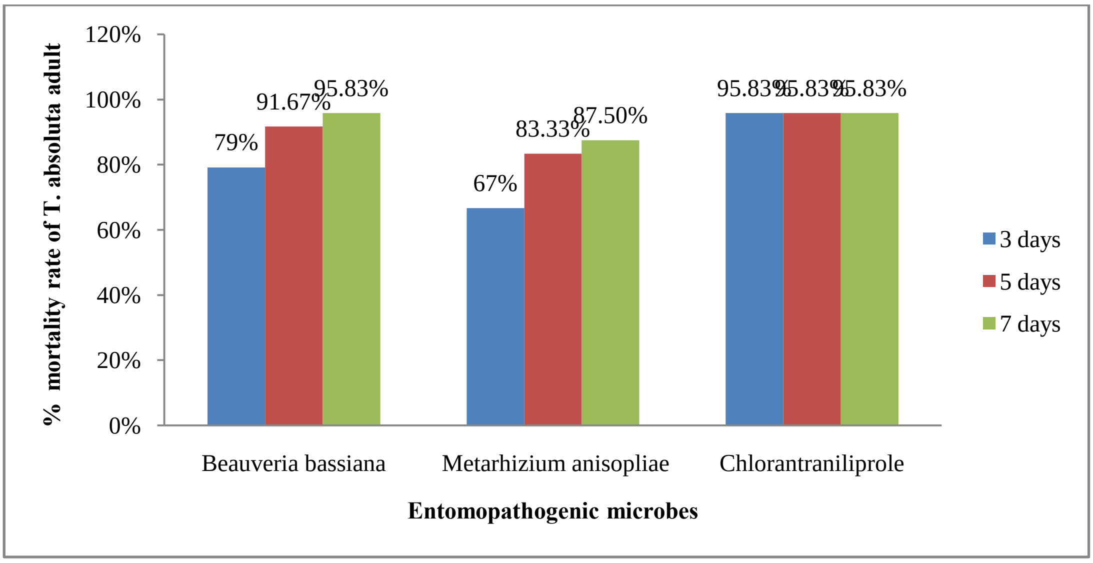


Fig. 4 : Mortality of *T. absoluta* adult using Entomo-pathogenic microbes (Tadele and Emana, 2017b)

Similarly, a study on the efficacy of three different entomo-pathogenic nematode (EPN) *Heterorhabditis bacteriophora* (Poinar), *Steinernema carpocapsae* (Weiser) and *Steinernema feltiae* (Filipjev) against *T. absoluta* evaluated during 2013-2014 under laboratory conditions in Turkey showed that *S. feltiae* was the most efficient nematode species. The results revealed that such EPN had a good potential for the control of *T. absoluta* larvae outside the leaves (Turkoz and Kaskavalci, 2016).

Biological control

Biological control refers to the use of entomophagous insects, i.e. predators and parasitoids for the control of pest. It occupies a central position in IPM program because of its enormous and unique advantages, like it is safe, effective, environment friendly, sustainable and economical (Illakwahhi and Srivastava, 2017; Muniappan, 2016). Zappala *et al*. (2013) reported *Nesidiocoris tenuis* (Reuter) as a cosmopolitan predator of *T. absoluta.* It is recorded from Algeria (Dahliz *et al.*, 2013), Cyprus, Egypt, France, Jordan, Iran (Sohrabi and Hosseini, 2015), Israel, Italy, Morocco, Spain and Turkey (Zappala *et al*., 2013). Guenaoui and Dehliz (2015) reported *Macrolophus pygmaeus*, *Nesidiocoris tenuis* (Reuter), *Orius* spp. as effective predator and *Necremnus artynes* (Walker), *Hemiptarsenus zilahisebessi* Erdos, *Neochrysocharis Formosa* (Westwood), *Bracon hebetor* Say and *Stenomesius* sp. as potential parasitoid in arid region of Algeria.

Cabello *et al.* (2012) reported two species, *Trichogramma achaeae* (Nagaraja and Nagarkatti) and *Trichogramma urquijoi* (Cabello Garcia) for controlling *T. absoluta*, among which, *T. achaeae* was found more effective for controlling *T. absoluta* populations. Zouba *et al*. (2013) found the parasitism rates of *T. absoluta* eggs to be 63.92% and 57.05% for *Trichogramma bourarachae* Pintureau & Babault and *Trichogramma cacoeciae* Marchal, and damage reduction of 87.62% and 78.89%, respectively in the greenhouse. However, Zekeya *et al.* (2017a) from Sub-Saharan Africa reported *Trichogramma pretiosum* Riley as a successful parasitoid. The authors also reported that *T. absoluta* egg parasitoids originate in the family Trichogrammatidae, Encyrtidae and Eupelmidae. Chermiti and Abbes (2013) reported two ectoparasitoid species attacking and developing on *T. absoluta,* that are *Bracon* sp. (Hymenoptera: Braconidae) and *Necremnus* sp. near *artynes* (Hymenoptera: Eulophidae) where, *Bracon* sp. was the most abundant with average parasitism rates of up to 25.5%.

In Tunisia, a research on newly adapted parasitoid for organic tomato production found two ectoparasitoid species attacking and developing on *T. absoluta,* that are *Bracon* sp. (Hymenoptera: Braconidae) and *Necremnus* sp. near *artynes* (Hymenoptera: Eulophidae) where, the eulophid wasp was the most abundant with average parasitism rates of up to 25.5% (Chermiti and Abbes, 2013). To examine the effectiveness of individual and combined use of predatory insect, *Nesidiocoris tenuis* Reuter (Hemiptera: Miridae) and the egg parasitoid, *Trichogramma evanescens* Westwood (Hymenoptera: Trichogrammatidae) as biological control measures for *T. absoluta,* an experiment was carried out in Turkey in year 2012-13 and 2013-14. The experiment showed that *N. tenuis* alone was effective to reduce the *T. absoluta* infestation by about 90% in tomato fruit. However, combined use of *N. tenuis* and *T. evanescens* gave higher percentage of damage reduction, i.e. about 95% in tomato fruit (Keçeci and Öztop, 2017).

However, *N. tenuis* is one of the most controversial dicyphines as a bio-control agent because of the injuries it causes to tomato crops. It was reported that *N. tenuis* caused flower abortion up to 50% when it occurred at densities of about 2 individuals per plant and the whitefly numbers were almost negligible in greenhouses (Sanchez, 2008). This indicates that the damage caused by bug to the plant is more, when the insect host is absent. Further, authors revealed that compartments with the highest abortion rates had heavier and bigger fruit and the yield was not significantly different from the controls. The yield reduction was estimated at fruit abortion at rates ≥27.7%, which corresponded to 566 cumulative number of *N. tenuis* (CNN) per plant or 32.11 CNN per leaf. Therefore, *N. tenuis* is considered as a useful predator of small pests in tomato crops if kept under these thresholds. Similarly, low damage potential of *N. tenuis* on tomato shoots or leaves and negligiable flower abortion was recorded by Perdikis *et al.* (2009) when bug was applied at the densities of 16 and 32 young nymphs (of the 1st, 2nd or 3rd instar), 16 and 24 large nymphs (of the 4th or 5th instars) and finally 16 and 32 adults of un- known age per cage.

Researchers have found greater effectiveness of mass trapping (Braham *et al.*, 2013), similar performance of botanical extract (Harbi *et al.*, 2013) and biological agents (Ameni *et al.*, 2013; Tadele and Emana, 2017b)) over the chemical method of *T. absoluta* control. These methods which are the component of IPM are found cost effective over the chemical method of control. A study carried out in Egypt to evaluate the efficacy of integrated control methods against *T. absoluta* in tomato variety Nili in year 2014 showed the highest yield production, production costs and cost benefit in the plot using egg parasitoid *Trichogramma bactrae* Nagaraja released five times combined with mass-trapping, followed by plot using bio-rational solution along with mass trapping. On other hand, plot using insecticides gave the lowest yield production with the highest costs (Goda *et al.*, 2015). This indicates that IPM technique apart from being eco-friendly and sustainable, is also cost effective.

CONCLUSION AND RECOMMENDATION

T. absoluta is a looming problem in tomato production in the mid hills and plains of Nepal. This recently emerged pest has become a pest of major economic importance causing up to 100% damage. The havoc caused by the pest demands immediate action. The invasive pest is found to develop pesticide resistance against the application of chemical pesticide in the other part of world. Owing to many other side effects of chemical pesticide application scientist and researchers have been seeking for an alternative management practices, which lower the damage of *T. absoluta* along with environment sustainability. Crop rotation, removal of alternate host, inter-cropping with coriander and gallant soldier, use of pheromone traps, plant based pesticide, entomophagous and entomopathogenic organism are some measures, which can be adopted for pest management. Efficacy of mass trapping over chemical control, high effectiveness of botanical extract and entomo-pathogenic microbes, like *Metarhizium anisopliae* and *Beauveria bassiana* for larval mortality, use of entomophagous insects, like *Nesidiocoris tenuis*, *Trichogramma* sp. for reduced infestation in plant and long term effect of these practices makes IPM beneficial and effective over chemical control. Similarly, cost efficacy of IPM over chemical control makes the practice easy for adoption for rural marginal farmers. However, farmers lack proper knowledge about the implementation and advantages of IPM. Therefore, awareness programs should be carried out for promoting the use of IPM techniques in different regions of the country. A detailed research study across the nation is necessary to access the pest problem and native natural enemy of the pest. Government should encourage farmers implementing IPM measures by providing subsidy or other measures.. Study should also be directed to define the economic thresholds and intervention levels for chemical control, as a last option. For the effective control, there is a need to establish *T. absoluta* monitoring program and proper quarantine regulation in non-invaded areas. Government along with other stakeholders should form a task force for implementing the strategies to control and eliminate *T. absoluta* completely.

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