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Efficacy of Commercial Insecticides against Tomato Leaf Miner *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in Palpa, Nepal

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A R T I C L E I N F O

Research Article

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A B S T R A C T

A survey and field experiment were conducted to evaluate the efficacy of commercial insecticides against tomato leaf miner [*Tuta absoluta* (Meyrick)(Lepidoptera: Gelechiidae)] under farmer's field condition in Palpa, Nepal from February 2018 to April 2018. It consists of seven treatments replicated three times. The treatments included: Abamectin 0.15% EC (dose: 0.3ml/liter), Imidachloprid 17.8% SL (dose: 0.3ml/liter), Spinosad 45% SC (0.3ml/liter), Azadirachtin 300 ppm (5ml/liter), Chlorantraniliprole 18.5% SC (0.3ml/liter), Emamectin benzoate 5% SC (2gm/liter) and control. Treatments were applied two times at 12 days interval. From the farmer survey, *Tuta absoluta* was identified as the major production problem of the study area. The field experiment revealed that there was a significant effect of insecticides in larval mortality and damage reduction. The lowest percentage of leaves damage was obtained in spinosad followed by chlorantraniliprole and emamectin benzoate and the lowest fruits damage was obtained in chlorantraniliprole followed by spinosad and emamectin benzoate. Similarly, the lowest larval population in both leaves and fruits was observed in chlorantraniliprole followed by spinosad and emamectin benzoate. Average mining in infested leaves and fruits was found non-significant at all days of observation. The rate of larval population reduction over control was found highest in chlorantraniliprole followed by spinosad and emamectin benzoate. Thus, chlorantraniliprole, spinosad and emamectin benzoate were superior insecticides for management of *Tuta absoluta* in the field condition.

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Introduction

Nepal is an agricultural country where the majority of people (65.6%) directly depend on agriculture and contribute less than one third (27.6%) of total Gross Domestic Product (GDP) (MOF, 2017). **V**egetable crops are an essential component of sustainable development, with a significant contribution to food security, nutritional balance and income source for resource-poor growers, especially in urban and peri-urban areas (FAO, 2012). Tomato is the 3rd important vegetable cultivated in 21,389 ha with a production of 400674 Mt and productivity of 18.73 Mt/ha in Nepal (MoAD, 2016).

The major insect-pests of field cultivated tomato were tomato fruit borer (*Helicoverpa armigera*), leaf miner (*Liriomyza trifolii*), and whiteflies (*Bemisia tabaci*) which can spread tomato yellow leaf curl virus. In addition to this, the tomato leaf miner (*Tuta absoluta)*, has been recently introduced to Nepal. The cause of long-distance dispersal is through packaging material coming from infested countries (Potting et al., 2013).

The tomato leaf miner (*Tuta absoluta*), native to South America is a serious threat to world's tomato production (Chidege et al., 2016) in both open and greenhouse condition. Larvae feed on the mesophyll of the leaf leaving only the epidermis intact with its faeces, which subsequently widens and then the damaged tissue dries. Under intense attack, the damaged leaves turn yellow, wither, and senescence; the fruits are destroyed; and the plant ultimately dies (Maluf et al., 1997). The yield and fruit quality are both considerably impacted by direct feeding as well as secondary pathogens entering into the host plants through wounds made by the pest (Kaoud, 2014).

The main host plant of *Tuta absoluta* was tomato (*Solanum lycopersicum* L.), but solanaceous cultivated plants such as potato (*Solanum tuberosum* L.), eggplant (*S. melongena* L.), pepper and hot pepper (*Capsicum* spp.) and wild plants *Solanum nigrum* L. and *Datura stramonium* L. (Estay, 2000) were the alternative host of the pest. Besides, it has also been reported from plants of Fabaceae family-like *Phaseolus vulgaris*, *Vicia faba*, *Vigna unguiculata* and *Medicago sativa*, which are commonly cultivated plants in Nepal (Bajracharya et al., 2016; Abdul-Ridha et al., 2012).

It was first detected in Ethiopia in 2012 (NAPPO, 2013). It was recorded from Maharashtra (India) and Nepal during October 2014 and May 2016 respectively (Bajracharya et al., 2016) from an altitude ranging from 725 masl to 1664 masl which defines the diversity of the pest. Since then, it had gradually spread almost all over the country. Srijana and Samjhana hybrids were worst affected variety of tomato. It was detected in 16 districts of Nepal among which 14 were middle hill districts and 4 were terai districts i.e Kailali, Saptari, Banke and Dang (Sah, 2017).

Tuta absoluta is a holometabolous insect which comprises four development stages viz. egg, larva, pupa and adult, and is completed within 24 days at 27°C (NAPPO, 2013). It has high reproductive potential and its life cycle ranged from 24 to 76 days, depending on the environmental conditions (Arnó and Gabarra, 2010). The adult lay its egg on the underside of leaves, buds, stems and calyx of unripe fruits singly or in batches. The newly deposited eggs are oval and creamy white in colour (Estay, 2000) then turn to yellow and finally black before hatching (Salama et al., 2014). Pupation may take place in the soil or on the leaf surface, stems, flower, fruits (Torres et al., 2001) or within the mines. They are brown in colour, which are initially green (Estay, 2000) and 6mm in size. Pupation completes in 10 days. Adults are small moths having a body length of 5-7mm and wingspan of about 8-10mm. Adults are mottled grey (Estay, 2000) or brown or silver in colour.

Tuta absoluta infests all the aboveground parts of the plant in each developmental stage. All stages of *Tuta absoluta* are found throughout the growing season under greenhouse condition (USDA-APHIS, 2011). The mines in the leaves form whitish and irregular spots which are found covered with droppings. It affects more in young fruits (MOAD, 2016).

Economic losses due to *Tuta absoluta* in tomato have been reported to be up to 100% in some countries in Africa particularly Sudan, Kenya, and Ethiopia. Chidege et al. (2016) reported a yield loss of 80-100% by this pest from countries in Northern and Western Africa. According to Sah (2017), the pest is likely to cause 80-100% tomato yield loss and financial loss of over 50 million USD. According to Muniappan (2015), *T. absoluta* had already infested 1.0 M ha of tomato cultivated area (22% of the total cultivated surface) out of 4.4 M ha in 2011.

In Spain, pesticides were applied 15 times more per season in the first year of introduction and cost went up by 450 Euros per hectare due to use of costly insecticides. The tomato pest management cost will go up by $500 M per year if the rest of the world infested by *Tuta absoluta* (Muniappan, 2015). Due to fear of failure of crop due to this pest, farmers are demotivated in tomato farming because of increased costs and losses in tomato production (Sah, 2017).

The most widespread and successful applications of sex pheromones concern their use in detection and population monitoring (Witzgall et al, 2010). The most common pheromone traps used for trapping of *Tuta absoluta* are water traps, which are easier to maintain and less sensitive to dust than Delta or light traps and also have a larger trapping capacity than Delta traps. Water traps consist of a plastic container holding water and a pheromone lure. The lure is secured above the water with a wire attached at both ends of the container. A small amount of vegetable oil or soap should be added to the water to reduce surface tension and limit water evaporation so that insect is trapped in water and cannot escape out from surface. This type of trap can capture large numbers of adult males without becoming saturated with insects (USDA-APHIS, 2011). The important elements related to trap placement are trap height and position concerning vegetation (Howse, 1998).

The pheromone traps can be used for pest detection, population monitoring (Harizanova et al., 2009), mass annihilation and mating disruption (Megido et al., 2013).

Neem oil (Azadiractin) is contact or systematic insecticide. Neem plant contains several active metabolites such as alkaloids which can control insect pests (Zekeya et al., 2016). It is used when there is the low infestation of *Tuta absoluta* larva or greater than 5 moths are trapped per day in any pheromone trap (Sah, 2017). At low infestation level, *Bacillus thuringensis*is is recommended to use in conjunction with Azadiractin. Hence, this research was conducted to find out the effective chemical control measures against *T. absoluta* in field condition.

Materials and Methods

The farmer's survey and field experiment were conducted for this study.

Farmer Survey

Farmer survey was done to identify the prevailing problem of tomato production, find the severity of *Tuta absoluta* and control measures currently being deployed by farmers for its management.

Selection of Study Area

The study was conducted in Tansen Municipality, Palpa district in western hills of Nepal. The command area under Prime Minister Agriculture Modernization Project (PMAMP), Project Implementation Unit, Vegetable Zone, Palpa was purposively selected as it includes Tansen Ward No. 7, 8 and 9, which were the major vegetable producing areas and worst hit by *Tuta absoluta* in the previous year.

Preliminary Survey

The pre-research field visits were conducted to gather preliminary information about the status of vegetable farming. It includes major vegetables cultivated, the status of tomato farming, the status of diseases and insects and the status of *Tuta absoluta* in tomato cultivation. This information was used to prepare the interview schedule and designing the experiment.

Interview Schedule Design

The simple interview schedule was developed including the information on major production problems, the status of *Tuta absoluta* and management practices adopted to control it.

Pre-testing

The interview schedule was pre-tested before administering to the actual respondents for checking the reliability and validity of the interview schedule. The pre-testing was done on 10 percent respondents near to study area. The corrections were made in the final interview schedule.

Household Interview

Thirty commercial tomato growers of Tansen Municipality Ward No. 7, 8 and 9 were interviewed to avail the information. It includes the major hindrance on their field caused by *Tuta absoluta* and farm-level management strategies adopted by them to manage the pest. A Focused Group Discussion (FGD) and was also conducted with representative farmers from all affected areas.

Field Experiment

Selection of Experiment Site

The field experiment was conducted on Tansen-7, Palpa to know about the effectiveness of different chemical pesticides against *Tuta absoluta*. Palpa district ranges from 157 to 1936 meters above the mean sea level. The geographic location of the field experiment site was 21º51' N and 83º32' E at an altitude of 982 meters from mean sea level. The research plot was 4 km south of Tansen bazaar.

The average annual rainfall in Palpa was 1903 mm, with the higher frequency of rainfall noticed from June to August. About 80% of total rain is received due to the monsoon. The average summer temperature is 23°C while that of winter is 14°C. However, the maximum and minimum temperature can range between 32°C to 2°C.

Field Experiment Design

The experiment was laid out at the tomato field of Nava Prativa Krishi Tatha Pashupalan Farm, Tansen– 7. The determinant variety of tomato named Dalida, with a life span of 54 days was planted. The field was laid out in Randomized Complete Block Design (RCBD) with seven treatments replicated three times. It consists of 21 plots. The six different chemical insecticides (most of them have biological origin or low toxicity) and control was used as treatment.

Layout of Field

Since the research was commenced on the farmer's field, no observations were made regarding the soil testing, manuring and fertilization, and other initial stage cultural operations used. However, plot size was maintained at $2.25m^2$ (1.5m×1.5m) with the row to row spacing and plant to plant spacing of 30 cm each. Spacing between both the replication and treatment was maintained at 50 cm with a field margin of 50 cm each on all sides. Thus, the total area of research field was 94.25 m^2 with total length and breadth of experimental design 14.5 m and 6.5m respectively (Figure 1, Table 1).

Application of Treatments

The first application of treatments made on 54 days old tomato plants. Pre-spray observations and data collection were made one day before the application of treatments. The second spray was made 12 days after the first spray while the third spray was made on 12 days after the second spray.

Syringes were used to measure the volume of liquid insecticides for the formulation, while 2gm spoon was used to measure powdery insecticide. Knapsack sprayer was used for the application of insecticides.

Observation of the Parameters

Five central plants from each plot were tagged as sample plants for observation and data were collected. Data were collected before first spray and 6^{th} and 12^{th} day after each successive spray. After collection of data of 12^{th} day of the previous spray, following spray was made on the same day.

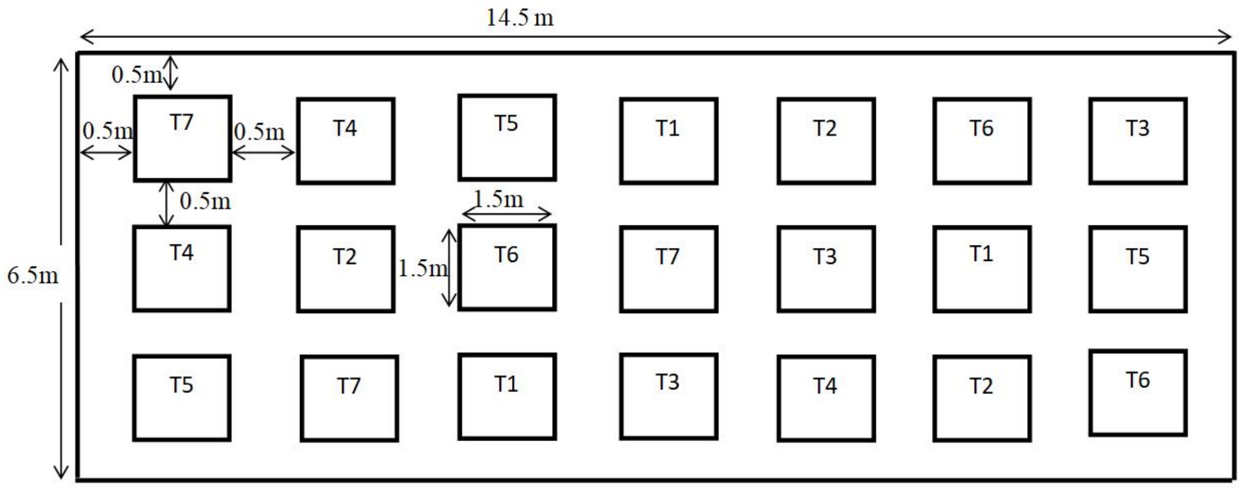

Figure 1. Layout of the research field at Tansen, Palpa

Table 1. Details about the treatments used in the field experiment

T	Trade name	Chemical Name	Dose	Type
T1	Biotrine	Abamectin 0.15% EC	0.3ml/litre	Bacterial origin-contact and stomach toxicity
T2	Acemepride	Imidachloprid 17.8 % SL	0.3ml/litre	Neo-nicotinoid chemical- systemic
T3	Tracer	Spinosad 45% SC	0.3 ml/litre	Bacterial origin-contact and ingestion toxicity
T4	Neemix	Azadirachtin 300 ppm	5ml/litre	Neem plant origin-systemic
T5	All chlora	Chlorantraniliprole 18.5% SC	0.3 ml/litre	Synthetic chemical- contact and ingestion toxicity
T6	Kingstar	Emamectin benzoate 5% SC	2 gm/litre	Synthetic-contact and stomach toxicity
T7	Control	Water spray		

T: Treatment

The observation parameters are as follows:

Percentage of leaves infested

The total number of leaves and number of infested leaves in sample plants were counted after every 6th and 12th day of each spray. These data were collected following non-destructive method i.e. the leaves were not picked out of the plant while counting. The percentage of leaves infested (PLI) was calculated as:

$$PLI(\%)= \frac{NLSP}{TLSP} \times 100$$

NLSP : Number of infested leaves in sample plants
TLSP : Total number of leaves in sample plant

Percentage of fruits infested

The total number of fruits and the number of infested fruits in sample plants were counted after every 6th and 12th day of each spray. These data were collected following the destructive method i.e. the fruits were picked out of the plant for counting. The percentage of fruits infested (PFI) was calculated as

$$PFI(\%)= \frac{NFSP}{TFSP} \times 100$$

NFSP : Number of infested fruits in sample plants
TFSP : Total number of fruits in sample plants

Average mining per leaf

Five infested leaves from each sample plants were picked out randomly and the number of mining in each leaf was counted from which average mining per leaf (AML) was calculated.

$$AML= \frac{T1}{N1}$$

T1 : Total number of leaf minings counted in infested sample leaves of each sample plant
N1 : Number of infested leaves taken to count minings

Average mining per fruit

Five infested fruits from each sample plants were picked out randomly and the number of mining in each fruit were counted from which average mining per fruit (AMF) was calculated.

$$AMF= \frac{T2}{N2}$$

T2 : Total number of fruit minings counted in infested sample fruits of each sample plant
N2 : Number of infested fruits taken to count mining

Average live larva per leaf

Sample infested leaves from each sample plants were picked out randomly and the number of larva in each leaf was counted from which average larva per leaf (ALL) was calculated.

$$ALL= \frac{T3}{N3}$$

T3 : Total number of live larva counted in infested sample leaves of each sample plant
N3 : Number of infested leaves taken to count live larva

Average live larva per fruit

Sample infested fruits from each sample plants were picked out randomly and the number of larva in each fruit were counted from which average larva per fruit (ALF) was calculated.

$$ALF= \frac{T4}{N4}$$

T4 : Total number of live larva counted in 5 infested sample fruits of each sample plant
N4 : Number of infested fruits taken to count live larva

Calculation of Percentage Reduction over Control (PROC)

The mean percentage of reduced larva population due to treatments was calculated as the percentage reduction over control (PROC). (*Abbott's* 1925)

$$\% \text{ population reduction} = [1- (\frac{Ta}{Tb} \times \frac{Cb}{Ca})] \times 100$$

Where,
T_a : Post-treatment population in treatment
T_b : Pre-treatment population in treatment
C_b : Pre-treatment population in control
C_a : Post-treatment population in control

PROC helps to understand the comparative reduction of larval population by each treatment regarding population in control in terms of percentage. This, in other sense, gives the measure of comparative effectiveness of treatments.

This formula was used to calculate PROC of the larval population both in infested fruits and infested leaves. 12 day's data after the first spray was used to calculate PROC after the second spray.

Statistical Analysis

The information collected from various sources was coded, entered and analyzed using Microsoft-Excel, Statistical Package for Social Science (SPSS) version 16 and Genstat. Quantitative data were represented in tables, bar diagrams, and pie-charts. Descriptive method was used for qualitative data.

In the field-based experiment, the initially collected data were entered in MS-Excel, where data tabulation, graphs and figures were structured. Data analysis was done by using Genstat. For mean separation, Duncan multiple range test was carried out at 5% level of significance.

Results and discussion

Farmer Survey

Production Problem Ranking in Tomato

Commercial tomato farmers of Tansen, Palpa, have had many problems related to production. The major problems were insects, diseases, weather-related hazards, unavailability of inputs and lack of technical know-how. The problems were ranked based on the Likert scale. The severity index showed that the insect was the most severe problem with an index of 0.96 followed by diseases with an index of 0.78. Weather-related hazard was the third most severe problem with an index of 0.53. Similarly, lack of technical know-how and unavailability of inputs was found as the fourth and the fifth problem with an index of 0.39 and 0.35 respectively (Table 2).

Table 2. Problem ranking in tomato production in Tansen, Palpa, 2018

Problems	Level of problem					Total	Weight	Index	Rank
	1	0.8	0.6	0.4	0.2				
Insect	25	4	1	0	0	30	28.8	0.96	I
Disease	3	22	4	1	0	30	23.4	0.78	II
Weather-related hazards	1	2	14	11	2	30	15.8	0.53	III
Unavailability of inputs	1	0	4	10	15	30	10.4	0.35	V
Lack of technical know-how	0	2	7	8	13	30	11.6	0.39	IV

Table 3. Insect pest severity ranking in tomato production in Tansen, Palpa, 2018

Problems	Level of problem					Total	Weight	Index	Rank
	1	0.8	0.6	0.4	0.2				
Tomato Leaf Miner	15	11	4	0	0	30	26.2	0.87	I
Tomato Fruit Borer	9	13	7	1	0	30	24	0.80	II
Cutworm	6	6	11	5	2	30	19.8	0.66	III
Aphids	0	0	4	10	16	30	9.6	0.32	V
Whitefly	0	0	4	14	12	30	10.4	0.35	IV

Table 4. Disease severity ranking in tomato production in Tansen, Palpa, 2018

Problems	Level of problem				Total	Weight	Index	Rank
	1	0.75	0.5	0.25				
Late Blight	28	2	0	0	30	29.5	0.98	I
Tomato wilt	1	15	13	1	30	19	0.63	II
Damping-off	1	13	6	10	30	16.25	0.54	III
Viral Diseases	0	0	11	19	30	10.25	0.34	V

Insect Pest Severity Ranking in Tomato Production

The major insects infesting the tomato crop was tomato leaf miner (*T. absoluta)* with an index value of 0.87. Similarly, tomato fruit borer was found the second most severe insect with an index value of 0.80 while the cutworm was third most severe insect with an index value of 0.66. Similarly, whitefly and aphids were found the least severe insects with an index of 0.35 and 0.32 respectively. The result aligns with those obtained from the focused group discussion with commercial tomato growers of the region (Table 3).

Diseases Severity Ranking in Tomato Production

The severity index showed that among diseases, late blight was the most severely affecting the profitability of tomato with an index of 0.98. Tomato Wilt was found to be the second most severe diseases with an index value of 0.63. Similarly, damping off and viral diseases was found least severe with an index of 0.54 and 0.34 respectively (Table 4).

Ranking of Tuta absoluta out of many other Problems

Tuta absoluta was found to be the most problematic among all the problems as reported by 60% of the respondents. Similarly, 23.33% farmer's insight that the *Tuta absoluta* was as problematic as *Helicoverpa armigera* and Late blight disease (*Phytophthora infestans*) while only 6.67% and 3.33% farmers reported it to be fewer problematic and least problematic of all in tomato production than other problems (Figure 2). A similar result was obtained from other infested districts as *T. absoluta* was found to be most serious among all other problems of tomato production (Bajracharya et al., 2016).

Management Practices Followed by Farmers for T. absoluta

The farmers of Tansen, Palpa have been practising different methods like cultural, physical, mechanical and chemical for control of *Tuta absoluta* in the field condition. It was found that chemical insecticides (99%) were the most frequented management practices. It was followed by pheromone traps (72%), botanical insecticides (69%), cultural methods (64%), mechanical methods (42%) and physical methods (21%) (Figure 3).

The higher use of chemical insecticides was due to better control and easy to use than other methods. Moreover, the use of pheromone traps and botanical insecticides like azadirachtin was due to subsidy provided by PMAMP, Vegetable zone, Palpa to the farmers.

A similar result was reported by (Sah, 2017) in Kavre district, where 89 percent of respondent used chemical pesticide. Maximum use of chemical pesticide was related to its effectiveness and ease of use. It also reported that the pheromone traps may be effective in controlling *T. absoluta* even in an intense infestation.

Major Insecticides Used by Farmers

It was found that 86.67% of farmers used Emamectin benzoate, 63.33% used Imidachloprid, 46.67% used Azadirachtin (Neem based insecticides), 33.33% farmers used abamectin and 26.67% used dichlorovus (Figure 4).

The higher use of emamectin benzoate was due to better crop protection. Moreover, comparative higher use of imidachloprid was reported due to local availability and promotion about its effectiveness from agro-vets. The use of Azadirachtin and Abamectin was increasing due to promotion by PMAMP, PIU, Vegetable zone, Palpa.

Field Experiment

The tomato plants in the research field were found to be infested with *Tuta absoluta* during the onset of research. Per-spray data were collected and treatments were applied twice at 12 days interval. Observations were made on 6^{th} and 12^{th} days after each spray. The results of the experiment were analyzed and presented with figures and tables where necessary.

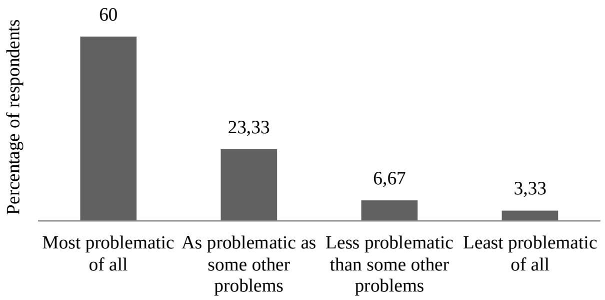

Figure 2. Ranking of *Tuta absoluta* out of other problems of tomato production in Palpa, 2018

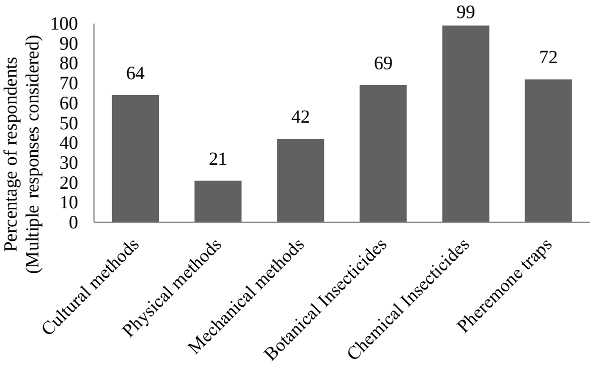

Figure 3. Management practices followed by tomato farmers to control *Tuta absoluta* in Palpa, 2018

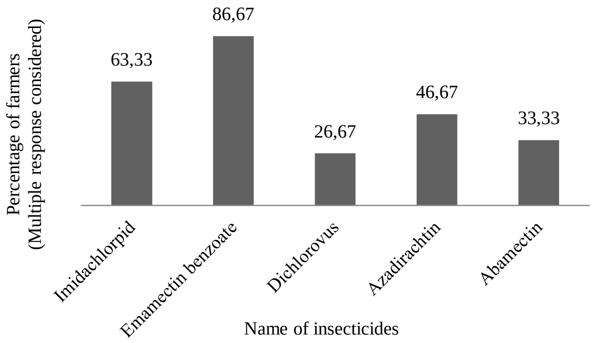

Figure 4. Chemical insecticides used by farmers for *Tuta absoluta* management in Tansen, Palpa, 2018

Table 5. Percentage of infected leaves on different days after spray at Tansen, Palpa, 2018

Treatment	Percentage of infected leaves			
	First Spray		Second Spray	
	6 DAS	12 DAS	6 DAS	12 DAS
Abamectin	27.26^{bc}	29.68^{bc}	28.72^{b}	32.84^{b}
Imidachloprid	29.98^{c}	33.41^{c}	33.89^{b}	34.73^{b}
Spinosad	17.77^{a}	18.35^{a}	18.73^{a}	17.41^{a}
Azadirachtin	29.79^{c}	33.99^{c}	31.94^{b}	35.79^{b}
Chlorantraniliprole	19.19^{a}	20.22^{a}	19.76^{a}	18.93^{a}
Emamectin benzoate	21.14^{ab}	25.23^{ab}	27.21^{b}	29.95^{b}
Control	34.36^{c}	37.71^{c}	41.65^{c}	45.71^{c}
Grand Mean	25.64	28.37	28.84	30.77
SEM(±)	2.260	2.535	2.403	2.225
LSD (0.05)	6.962***	7.810***	7.403***	6.855***
CV(%)	15.3	15.5	14.4	12.5

Note: Same letter with the means do not differ significantly at P=0.05 by DMRT, SEM: Standard error of mean, CV: Coefficient of variation, LSD: Least significant difference, ***: 0.1% level of significance, DAS: Days after spray

Percentage of leaves and fruits infested

At 6DAS of the first spray, the least infested leaves were found in spinosad (17.77%) which was statistically similar to chlorantraniliprole (19.19%) and emamectin benzoate (21.14%). Similarly, the highest infested leaves were found in control (34.36%) which was statistically similar to that of imidachloprid (29.98%), azadirachtin (29.79%) and abamectin (27.26%). Similar results were obtained at 12 DAS of the first spray with the least infested leaves found in spinosad (18.35%) and highest infested leaves found in control (37.71%) (Table 5).

At 6 days after the second spray, the least infested leaves were found in spinosad (18.73%) which was at par with chlorantraniliprole (19.76%). Similarly, the highest leaves damage was found in control (41.65%). Similar results were obtained at 12 days after the second spray with lowest infestation found in spinosad (17.41) and chlorantraniliprole (187.93) and highest infestation found in control (45.71) (Table 5).

At 6 days after the first spray, the lowest percentage of fruits infested was found in spinosad (5.622) which was statistically at par with emamectin benzoate (6.008), imidachloprid (8.493) and chlorantraniliprole (8.588). The highest percentage of infested fruits was found in control (14.934) and azadirachtin (13.263) and they were found statistically similar (Table 6).

At 12 days after the first spray, similar results were obtained with the lowest fruit infestation found in spinosad (1.793), which was statistically at par with chlorantraniliprole (2.220). Highest fruit infestation was found in control (7.306) (Table 6).

At 6 days after the second spray, the lowest infestation of fruits was found in chlorantraniliprole (0.575), which was statistically at par with spinosad (0.592). The highest infestation of fruits was found in control (9.149) (Table 6).

At 12 days after the second spray, the lowest infestation of fruits was found in chlorantraniliprole (0.133) followed by spinosad (0.181) and emamectin benzoate (0.918), which were also found to be significantly similar. Highest fruits infestation was found in control (8.865) (Table 6).

From the results above, it is clear that chlorantraniliprole and spinosad were found most effective for reducing the leaf and fruit damage due to *Tuta absoluta* in the farmer's field condition. Also, all the treatment gave better results than control.

The results for leaves and fruits damage are following the findings of Bajracharya et al. (2016), who reported that chlorantraniliprole and spinosad were effective for reducing damage and achieving higher larval population control in field condition.

Average Larval Population Per Infested Leaves and Fruits

The result shows that the average live larval population per infested leaves was found to be highly influenced by the application of treatments at all days after spray.

At 6 days after the first spray, the lowest larval population on leaves was found in chlorantraniliprole (0.1573) which was statistically at par with spinosad (0.2526) and the highest larval population was found in control (0.6823). Similar results were found at 12 days after the first spray, with lowest larval population obtained in chlorantraniliprole (0.0881) followed by spinosad (0.0889) which were also statistically similar. The highest larval population was found in control (0.7486) (Table 7).

Table 6. Percentage of infested fruits at different days after spray at Tansen, Palpa, 2018

Treatment	Percentage of infested fruits			
	First Spray		Second Spray	
	6 DAS	12 DAS	6 DAS	12 DAS
Abamectin	11.113^{bc}	4.435^{bc}	2.024^{b}	1.988^{c}
Imidachloprid	8.493^{ab}	3.581^{b}	2.695^{b}	1.267^{bc}
Spinosad	5.622^{a}	1.793^{a}	0.592^{a}	0.181^{a}
Azadirachtin	13.263^{cd}	5.335^{c}	3.787^{c}	1.510^{bc}
Chlorantraniliprole	8.588^{ab}	2.220^{a}	0.575^{a}	0.133^{a}
Emamectin benzoate	6.008^{a}	3.487^{b}	2.292^{b}	0.918^{ab}
Control	14.934^{d}	7.306^{d}	9.149^{d}	8.865^{d}
Grand Mean	9.72	4.02	3.02	2.12
SEM(±)	0.950	0.377	0.306	0.288
LSD (0.05)	2.928***	1.163***	0.942***	0.887***
CV(%)	16.9	16.3	17.6	23.5

Note: Same letter with the means do not differ significantly at P=0.05 by DMRT, SEM: Standard error of mean, CV: Coefficient of variation, LSD: Least significant difference, ***: 0.1% level of significance

Table 7. Average live larva per infested leaf at different days after spray at Tansen, Palpa, 2018

Treatment	Average larva per infested leaf			
	First Spray		Second Spray	
	6 DAS	12 DAS	6 DAS	12 DAS
Abamectin	0.3205^{b}	0.1746^{b}	0.1503^{bc}	0.0723^{ab}
Imidachloprid	0.5405^{c}	0.1687^{b}	0.1063^{ab}	0.0734^{ab}
Spinosad	0.2526^{ab}	0.0889^{a}	0.0457^{a}	0.0145^{ab}
Azadirachtin	0.3153^{b}	0.2735^{c}	0.2143^{c}	0.0758^{b}
Chlorantraniliprole	0.1573^{a}	0.0881^{a}	0.0390^{a}	0.0116^{a}
Emamectin benzoate	0.3059^{b}	0.1711^{b}	0.1052^{ab}	0.0393^{ab}
Control	0.6823^{d}	0.7486^{d}	0.7950^{d}	0.8723^{c}
Grand Mean	0.368	0.2448	0.2080	0.1656
SEM(±)	0.0426	0.01826	0.02318	0.01875
LSD (0.05)	0.1313***	0.05627**	0.07141***	0.05778***
CV(%)	20.1	12.9	19.3	19.6

Note: Same letter with the means do not differ significantly at P=0.05 by DMRT, SEM: Standard error of mean, CV: Coefficient of variation, LSD: Least significant difference, ***: 0.1% level of significance

Table 8. Average live larva per infested fruit at different days after spray at Tansen, Palpa, 2018

Treatment	Average larva per infested fruit			
	First Spray		Second Spray	
	6 DAS	12 DAS	6 DAS	12 DAS
Abamectin	0.9811^{b}	0.9226^{ab}	0.8651^{b}	0.7589^{bc}
Imidachloprid	1.0540^{b}	0.9578^{ab}	0.8370^{b}	0.7440^{bc}
Spinosad	0.7761^{a}	0.6111^{a}	0.4736^{a}	0.3333^{ab}
Azadirachtin	0.9930^{b}	0.9264^{ab}	0.8450^{b}	0.8029^{c}
Chlorantraniliprole	0.7867^{a}	0.5958^{a}	0.3333^{a}	0.2893^{a}
Emamectin benzoate	0.9474^{ab}	0.7460^{a}	0.4444^{a}	0.3889^{abc}
Control	1.0966^{b}	1.1868^{b}	1.2803^{c}	1.4562^{d}
Grand Mean	0.948	0.849	0.726	0.682
SEM(±)	0.0549	0.1175	0.0926	0.1364
LSD (0.05)	0.1691**	0.3620**	0.2852**	0.4203***
CV(%)	10.0	24.0	22.1	34.6

Note: Same letter with the means do not differ significantly at P=0.05 by DMRT, SEM: Standard error of mean, CV: Coefficient of variation, LSD: Least significant difference, ***: 0.1% level of significance

At 6 days after the second spray, the lowest larval population on leaves was found in chlorantraniliprole (0.0390) which was statistically at par with spinosad (0.0457) and emamectin benzoate (0.1052) with a highest larval population per leaves found in control (0.7950). At 12 days after the second spray, the highest larval population was found in control (0.8723). The lowest larval population was found in chlorantraniliprole (0.0116) which was statistically similar to spinosad (0.0145), emamectin benzoate (0.0393), abamectin (0.0723) and imidachloprid (0.0734) (Table 7).

The result shows that the average live larval population counted in infested fruits was found to be highly influenced by the application of treatments at all days after spray.

It was found that at 6 days after the first spray, the lowest larval population per infested fruit was found in spinosad (0.7761) which was statistically at par with chlorantraniliprole (0.7867) and emamectin benzoate (0.9474). Similarly, the highest larval population count was obtained in control (1.0966) which was also statistically similar with imidachloprid (1.0540), azadirachtin (0.9930) and abamectin (0.9811) (Table 8)

Similarly, on 12th day after the first spray, lowest larval count per infested fruit was obtained in chlorantraniliprole (0.5958), which was found statistically at par with all other treatments except control, which has a highest larval count (1.1868) (Table 8).

At 6 days after the second spray, the larval population was found to be lowest in chlorantraniliprole (0.333) which was statistically at par with emamectin benzoate (0.4444) and spinosad (0.4736). The highest larval population was found in control (1.2803). A similar result was obtained in 12days after the second spray, where chlorantraniliprole, spinosad and emamectin benzoate had a least larval population in fruits respectively while the control had the highest larval population (Table 8).

Above results were evident that chlorantraniliprole was most effective for reducing the larval population in both leaves and fruits. Spinosad and emamectin benzoate was also found to be similarly effective. According to Deleva and Harizanova (2014), azadirachtin, emamectin benzoate, spinosad and chlorantraniliprole caused 90-100% mortality in lab condition, which is following the findings of this study. The effectiveness of chlorantraniliprole against *Tuta absoluta* was due to its fastest action on feeding cessation and reduction in feeding damage. Bassi et al. (2009) reported that chlorantraniliprole was effective in stopping the feeding of the larva in a short time (few minutes to few hours) after ingestion.

Average number of mining per infested leaves and fruits

The application of treatments had no significant effect on the number of mining in infected leaves as well as fruits at any days after spray (Table 9, Table 10). Although the number of mining was directly associated with the larval population, despite the reduction of larval population by the use of chemical insecticides, there was the non-significant difference in the mining. This was due to the application of treatments after the field was already infested by *Tuta absoluta* as the empty mines created by the dead larva exist in the plant parts. This result was supported by the findings from Sallam et al. (2015), who reported that the post-infestation application of chemical insecticides didn't had a significant effect on mining percent reduction, due to presence of already created empty mines by the dead larva.

Population reduction over control (PROC) of larva in leaves and fruits

All the insecticides were able to reduce the population of larva in leaves after each spray (Table 11). The population reduction for the first spray was based on pre-spray data and the second spray was based on data observed in 12 days after the first spray.

At 6 days after the first spray, highest population reduction percentage was obtained in chlorantraniliprole (81.10%), followed by spinosad (62.83%) and abamectin (55.48%) while lowest reduction percentage was found in Imidachloprid (28.25%) and azadirachtin (46.75%) (Table 11).

At 12 days after the first spray, there was a greater reduction of larval population in all the treatments as compared to the previous day of observation. Highest population reduction was observed in chorantraniliprole (88.95%), followed by spinosad (88.08%) and emamectin benzoate (75.78%). Lowest population reduction was observed in azadirachtin (57.90%) (Table 11).

At 6 days after the second spray, it was found that highest population reduction was in spinosad (58.71%) and chlorantraniliprole (58.33%) followed by emamectin benzoate (41.45%) and the lowest reduction was observed in azadirachtin (26.23%). Similarly, at 12 days after the second spray, highest population reduction was observed in chlorantraniliprole (88.70%) and spinosad (86.01%) followed by emamectin benzoate (80.30%). Similarly, the lowest reduction percentage was observed in imidachloprid (64.11%) and abamectin (64.46%) (Table 11).

All the treatments were able to reduce the larval population of fruit after every spray.

Chlorantraniliprole was found continuously superior at reducing the larval population at each day of observation with 30.65% and 51.47% reduction observed at 6 and 12 days after the first spray. Similarly, 48.14% and 60.43% reduction was observed in 6 and 12 days after the second spray. Similarly, emamectin benzoate was found to be in second place, with a reduced rate of 18.30% and 40.56% at 6 and 12 days after the first spray. Likewise, 44.77% and 57.51% reduction was observed in 6 and 12 days after the second spray (Table 12).

Ayalew (2011) reported that chlorantraniliprole was most effective against *T. absoluta* due to its diamide ingredient which acts by modulating the ryanodine receptor. Insecticides with this mode of action were reported to had better efficacy against leaf miners due to their capabilities of reaching mining larva inside leaf by penetrating leaf surface.

Table 9. Average mining per infested leaf at different days after spray at Tansen, Palpa, 2018

Treatments	Average mining per infested leaf			
	First Spray		Second Spray	
	6 DAS	12 DAS	6 DAS	12 DAS
Abamectin	1.279	1.331	1.415	1.419
Imidachloropid	2.147	2.033	1.918	1.941
Spinosad	1.612	1.430	1.371	1.458
Azadirachtin	1.470	1.413	1.581	1.451
Chlorantraniliprole	1.297	1.385	1.387	1.409
Emamectin benzoate	1.330	1.308	1.340	1.234
Control	1.712	1.721	1.642	1.653
Grand Mean	1.550	1.517	1.522	1.509
F-test	NS	NS	NS	NS

Table 10. Average mining per infested fruit at different days after spray at Tansen, Palpa, 2018

Treatments	Average mining per infested fruit			
	First Spray		Second Spray	
	6 DAS	12 DAS	6 DAS	12 DAS
Abamectin	1.394	1.311	1.333	1.167
Imidachloprid	1.375	1.306	1.550	1.083
Spinosad	1.381	1.222	0.667	0.333
Azadirachtin	1.107	1.267	1.444	2.167
Chlorantraniliprole	1.176	1.000	1.000	0.333
Emamectin benzoate	1.056	1.333	1.333	1.333
Control	1.278	1.250	1.078	1.461
Grand Mean	1.252	1.241	1.201	1.13
F value	NS	NS	NS	NS

Note: Same letter with the means do not differ significantly at P=0.05 by DMRT, SEM: Standard error of mean, CV: Coefficient of variation, LSD: Least significant difference, NS: Non-significant, DAS: Days after spray

Table 11. Population reduction percentage of larva in infested leaves over control

Treatment	Pre-Spray	PROC of larva found in leaves							
		First Spray				Second Spray			
		6 DAS		12 DAS		6 DAS		12 DAS	
	Avg. Popln	Avg. Popln	PROC %	Avg. Popln	PROC %	Avg. Popln	PROC %	Avg. Popln	PROC %
Abamectin	1.839	0.952	55.48	0.524	77.67	0.451	18.92	0.217	64.46
Imidachloprid	1.944	1.622	28.25	0.526	78.78	0.319	42.92	0.220	64.11
Spinosad	1.754	0.758	62.83	0.267	88.08	0.117	58.71	0.043	86.01
Azadirachtin	1.528	0.946	46.75	0.821	57.90	0.643	26.23	0.228	76.21
Chlorantraniliprole	1.876	0.412	81.10	0.264	88.95	0.117	58.33	0.035	88.70
Emamectin benzoate	1.661	0.928	51.96	0.513	75.78	0.319	41.45	0.118	80.30
Control	1.761	2.047	0	2.246	0	2.385	0	2.617	0

Note: Avg: Average, Popln: Population, DAS: Days after Spray, PROC: Population reduction over control

Table 12. Population reduction percentage of larva in infested fruits over control

Treatment	Pre-Spray	PROC of larva found in fruits							
		First Spray				Second Spray			
		6 DAS		12 DAS		6 DAS		12 DAS	
	Avg. Popln	Avg. Popln	PROC %	Avg. Popln	PROC %	Avg. Popln	PROC %	Avg. Popln	PROC %
Abamectin	3.007	2.943	13.72	2.768	25.04	2.595	13.07	2.277	32.96
Imidachloropid	3.250	3.162	14.23	2.873	27.99	2.511	18.99	2.232	36.69
Spinosad	2.429	2.328	15.49	1.833	38.51	1.421	28.16	1.000	55.54
Azadirachtin	3.000	2.979	12.46	2.779	24.55	2.535	15.45	2.409	29.36
Chlorantraniliprole	3.000	2.360	30.65	1.787	51.47	1.000	48.14	0.868	60.43
Emamectin benzoate	3.067	2.842	18.30	2.238	40.56	1.333	44.77	1.167	57.51
Control	2.900	3.290	0	3.561	0	3.841	0	4.369	0

Note: Avg: Average, Popln: Population, DAS: Days after Spray, PROC: Population reduction over control

Conclusion

The *Tuta absoluta* was the major production problem of tomato farming in Tansen, Palpa and chemical insecticides are the most preferred control measures at field condition due to their superior performance and easiness to use. Among the insecticides used for the field experiment, chlorantraniliprole was found to be most effective for reducing larval population and its damage in leaves and fruits followed by spinosad and emamectin benzoate.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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