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Research Article

Integrated Pest Management of *Tuta absoluta* (Lepidoptera: Gelechiidae) in Tomato Field

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Abstract | The invasive South American leaf miner, *Tuta absoluta* (TLM) has recently been reported to cause serious losses to tomato in Punjab and Sindh provinces of Pakistan. Therefore, studies were conducted to evaluate the effectiveness of integrated management approach and conventional farmer practice (control) to restrict the economic damage of *T. absoluta*. The widely grown hybrid tomato variety (T-1057- Syngenta Pak Ltd.) was used in the study as two sprays of Flubendiamide 480 g/L was used in the control, whereas IPM treatment comprised of pheromone and golden colored light traps, spearmint as push (repellent) crop, garden cress as pull (attractant) crop, and spray with neem (only one spray during study) to keep the TLM infestation below threshold level. Spearmint and garden cress along with pheromone and light traps were installed since transplanting of tomatoes. The results indicated comparatively rapid increase in TLM infestation in control than IPM as two sprays of Flubendiamide were required for its management during week ten (mean infestation on leaves and fruits was 20.25±2.15 and 6.20±0.80, respectively) and sixteen (mean infestation on leaves and fruits as 15.15±1.35 and 12.75±1.08%, respectively). The maximum infestation of TLM in IPM treatment on leaves (18.93±1.84%) and fruits (8.05± 0.87%) during the week fourteen justified the only spray of neem to reduce its infestation. Thus, overall mean TLM infestation on tomato leaves and fruits over entire study duration was recorded in control and IPM treatments was 7.64±0.25 and 8.91±0.06%, and 3.79±0.15 and 2.77±0.12%, respectively. Significantly similar yields were obtained in both control (724.80±12.06 maunds per acre) and IPM treatments (736.40±10.48 maunds per acre). Overall, cost of production in control and IPM treatments was estimated as Rs.168,000/= and Rs.173,100/=, respectively, whereas total income generated Rs.652,320/= and Rs.662,400/=, respectively that resulted in almost same cost-benefit ratio of 1.00:2.88 and 1.00:2.83 in control and IPM treatments, respectively. Therefore, it is advised that adaptation of IPM module could significantly manage TLM infestation in tomatoes with less dependence on synthetic insecticides with same net returns.

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Links Researchers

Introduction

Tuta absoluta has been recently recorded from various tomato growing areas of Pakistan including Sindh province (Ishtiaq *et al*., 2020; Sadique *et al*., 2022; Gabol *et al*., 2023). Considering its invasive characteristics of high reproductive potential, voracious feeding, and rapid spreading capability necessitates its timely management (Jallow *et al*., 2020; Tarusikirwa *et al*., 2020; Shahini *et al*., 2021). Mostly the management of *T. absoluta* is done through the application of synthetic insecticides, but it did not get the desired results of the control of pest mainly due to the endocryptic nature of larvae that are protected insides the host tissues (Abdelmaksoud *et al*., 2020; Jallow *et al*., 2020). Moreover, the pest has also become resistant to many widely used pesticides (Grant *et al*., 2019; Mansour *et al*., 2019). Previous studies have also emphasized on the utilization of integrated approaches to reduce the infestation of *T. absoluta* with less or no reliance on the synthetic insecticides because of their adverse effects on the non-target organisms, human beings, and the environment (Desneux *et al*., 2007, 2022). As compared to open field conditions, IPM strategies were found to have achieved more satisfactory results under greenhouse conditions (Biondi *et al*., 2018). Moreover, recently agronomic based control management strategies involving modulation of irrigation and soil fertilization along with breeding of resistant varieties and use of various management strategies i.e., pheromone, light traps, push and pull crops, botanicals/ biorational and synthetic pesticides have enhanced the efficacy against insect pests including *T. absoluta* (Han *et al*., 2019a, b).

Therefore, a comparable study was conducted between farmer's practice and IPM module against *T. absoluta* under open field conditions to restrict its infestation on tomato leaves and fruits. Moreover, the impact of the two management modules was also determined on the tomato yield along their cost benefit ratio based on their cost of production and income generated.

Materials and Methods

Study location and cultivation of tomato

The study was conducted at a farmer's field located in the district Shaheed Benazir Abad, Sindh. The widely used and relatively resistant hybrid tomato variety (T-1057- Syngenta Pak Ltd.) was cultivated at its recommended dose of 150 grams per acre. All the agronomic practices were applied as per the recommendations.

Treatments

Two treatments were used in the study:

1. T1= Conventional farmers practice where management of *T. absoluta* was done using synthetic insecticide Flubendiamide 480 g/L as two sprays were required during the study.
2. T2= IPM practice that comprised of following components:

- Use of synthetic pheromone and golden colored light traps for early detection and monitoring of *T. absoluta* and the same were installed with the transplanting of tomato nursery.
- Intercropping of spearmint on alternate rows in tomatoes as push or repellent plants.
- Border cropping of garden cress as pull or attractant crop.
- Application of Neem extract when *T. absoluta* infestation reached threshold level (only a single spray of Neem extract was required in the IPM treatment).

Experimental design, data collection, and analysis

The experiment was laid down in a randomized complete block design as five replications were maintained for each treatment. The size of individual replicated was maintained at 100 ft^2. The data collection on *T. absoluta* was started since the transplanting of tomatoes by selecting five plants randomly per replication. The characteristic damage symptoms of *T. absoluta* were observed from all above-ground parts i.e., leaves, fruits, stems of the selected plants by counting the healthy and infested tomato parts to determine the infestation percentage using the following formula:

$$\text{Damage \%} = (\text{Number of infested part} / \text{total number of part}) \times 100$$

The yield data was also obtained by recording the entire harvesting of fruits from both the treatments. Moreover, cost benefit ratio was also calculated for both the treatments by using actual production and protection costs along with income obtained from the sale proceeds.

Analysis of Variance was used for the analysis of data, whereas LSD was used to separate the means with significant differences. The STATISTIX 8.1 computer software was used to carry out all the analysis.

Results

Impact of IPM and conventional farmer's practices on the mean infestation percentage of Tuta absoluta on tomato leaves

Figure 1 describes results regarding the impact of conventional farmer and IPM practices on the infestation percentage of *T. absoluta* on tomato leaves. *Tuta absoluta* started its infestation on leaves in both the treatments from second and third week of the tomato transplantation, respectively. The initial infestation of *T. absoluta* recorded in conventional farmer and IPM treatments was 0.50±0.19 and 0.90±0.14%, respectively and the same showed an increase in both the treatments afterwards. Comparatively, a rapid rise in *T. absoluta* infestation was recorded in conventional farmer treatment than IPM treatment which reached to 20.25±2.15% during the week ten after tomato transplanting and required the application of insecticide, Belt. Due to the insecticide application, *T. absoluta* infestation in conventional farmer treatment drastically reduced to 5.35±0.57% within two weeks of the application, however, it then gradually increased to reach up to 15.15±1.35% during 16th week of the transplantation. A second spray of Belt was carried out during week sixteen, considering the overall *T. absoluta* infestation of both tomato leaves and fruits. Thereafter, a further decline in *T. absoluta* infestation was recorded in the conventional farmer treatment that reached to 3.13±0.40% at the end of final harvesting during week twenty-four (Figure 1).

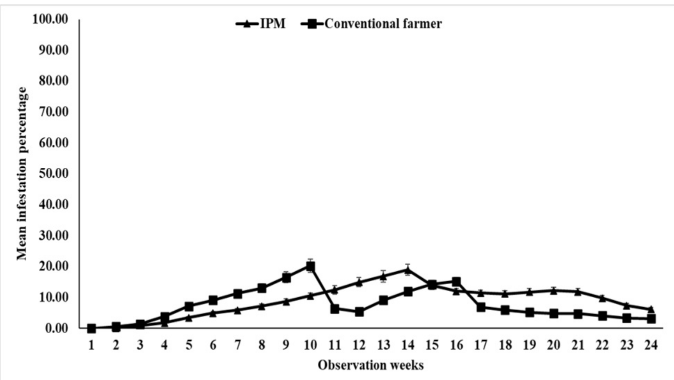

Figure 1: *Impact of integrated and conventional farmer's practices on the mean infestation percentage of Tuta absoluta on tomato leaves.*

In IPM treatment, *T. absoluta* infestation on tomato leaves was significantly lower than conventional farmer's practice and the same may be because of the combined effects of pheromone and light traps along with push (spearmint) and pull (garden cress) plants. Thus, only a single spray of Neem extracts was required during the week fourteen of the transplanting when the infestation of leaves reached 18.93±1.84%. After the application of Neem extracts, a sharp decline in *T. absoluta* infestation on tomato leaves was recorded that reached to 13.85±1.35% during week fifteen and the same decreased gradually towards final harvesting of tomatoes during the week twenty-four (6.10±0.61%) (Figure 1). Overall, a highly significant ($F = 16.36$, $P < 0.001$) difference was recorded in *T. absoluta* infestation on leaves between conventional farmer and IPM treatment over the entire growth period of tomatoes.

Impact of IPM and conventional farmer's practices on the mean infestation percentage of Tuta absoluta on tomato fruits

As compared to tomato leaves, comparatively lower level of *T. absoluta* infestation was noticed on tomato fruits that was first observed during week five and six after the transplanting in conventional farmer and IPM treatments, respectively (Figure 2). The starting infestation in conventional farmers and IPM treatments was 0.20±0.07 and 0.18±0.07%, respectively. Afterwards, the level of *T. absoluta* infestation in conventional farmer's treatment was significantly more than that of IPM treatment. The maximum *T. absoluta* infestation on tomato fruits (12.75±1.08%) in conventional farmer treatment was recorded during week sixteen after the transplanting, that justified the application of synthetic insecticide Belt. After the application of Belt, a sharp decline in *T. absoluta* infestation was observed on tomato fruits during the week seventeen (4.75±0.49%) and the same gradually declined towards the final harvesting of tomato during the week twenty-four (2.40±0.35%) (Figure 2). On other hand, in IPM treatment, due to the combined effect of light and pheromone traps along with push and pull crops, the maximum *T. absoluta* infestation on tomato fruits recorded was 8.05± 0.87% during the week fourteen after the transplanting (Figure 2). Statistically, a highly significant ($F = 16.69$, $P < 0.001$) variation was observed between conventional farmer and IPM treatments in respect to *T. absoluta* infestation on tomato fruits over the entire twenty-four weeks of the study.

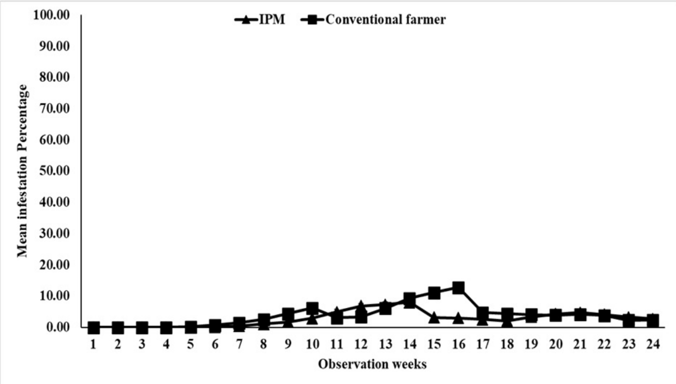

Figure 2: *Impact of integrated and conventional farmer's practices on the mean infestation percentage of Tuta absoluta on tomato fruits.*

Impact of IPM and conventional farmer's practices on the overall mean infestation percentage of Tuta absoluta on tomato leaves and fruits

Overall infestation of *T. absoluta* on tomato leaves and fruits observed in conventional farmers and IPM treatments is given in Figure 3. In contrast to tomato leaves, where significantly ($F= 42.20$, $P < 0.001$) higher infestation of *T. absoluta* was observed in IPM treatment (8.91±0.06%) than conventional farmers treatment (7.64±0.25%), tomato fruits suffered significantly ($F= 51.42$, $P < 0.001$) lower infestation in IPM treatment (2.77±0.12%) than the conventional farmers treatment (3.79±0.15%).

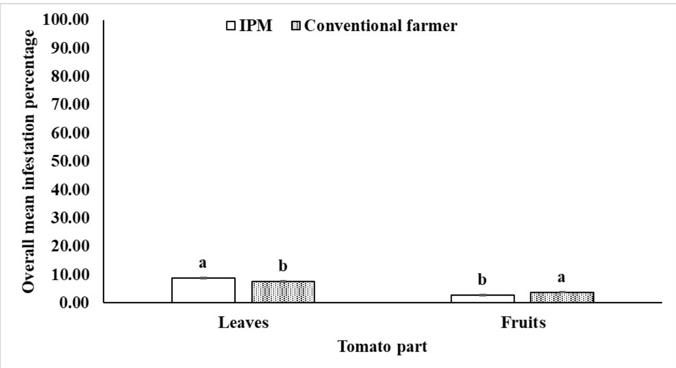

Figure 3: *Impact of integrated and conventional farmer's practices on overall mean infestation percentage of Tuta absoluta on tomato leaves and fruits.*
**Means with same letters are not significantly different (Leaves - LSD = 0.5515, P < 0.05; Fruits- LSD = 0.2781, P < 0.05).*

Impact of IPM and conventional farmer's practices on tomato yield in response to management of Tuta absoluta infestation

Considering the significant impact of IPM practices to lower *T. absoluta* infestation on tomato fruits, slightly higher yield was recorded in it (736.40±10.48 maunds per acre), but the same was not significantly ($F = 0.53$, $P = 0.4886$) different from the yield obtained in conventional farmers treatment (724.80±12.06 maunds per acre) (Figure 4).

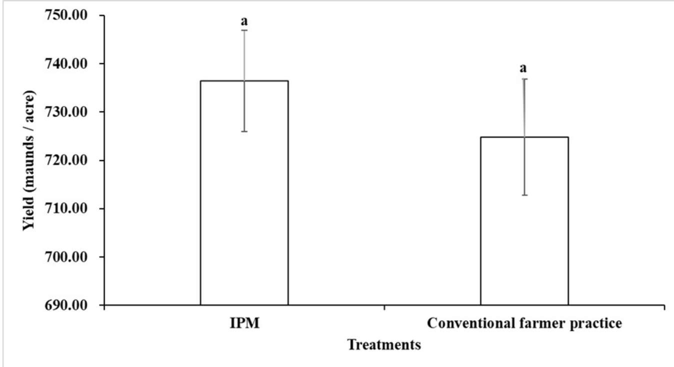

Figure 4: *Impact of integrated and conventional farmer's practices against Tuta absoluta on tomato yield.*
**Means with same letters are not significantly different (LSD = 36.853, P < 0.05).*

Table 1: *Cost benefit ratio of tomato grown under conventional farmer and integrated pest management strategies against Tuta absoluta.*

Expenditure/ Acre		**IPM module**	**Farmer practice**
A. Cost of production	**Rs.**	**Rs.**	**Rs.**
Land preparation	15,000	15,000	15,000
Tomato Seed	20,000	20,000	20,000
Transplanting	2,000	2,000	2,000
Inter-culturing	8,000	8,000	8,000
Fertilizer	45,000	45,000	45,000
Weedicides	0	0	0
Irrigation labor charges	5,000	5,000	5,000
Picking charges	30,000	30,000	30,000
Packing charges (plastic)	5,000	5,000	5,000
Other expenses (transportation)	20000	20,000	20,000
Miscellenous	10,000	10,000	10,000
Total of (A)		160,000	160,000
B. Cost of protection			
Neem extracts (labor charges)	2,000	2,000	0
Light traps	1,600	1,600	0
Pheromone traps	8,000	8,000	0
Push/ Pull crops	1500	1500	0
Chemical control- belt (2 sprays) + labor charges	4000	0	8,000
Total of B		13,100	8,000
Total cost (A±B)		173,100	168,000
C. Income			
Yield (Maunds)		736.00	724.80
D. Gross income	**900/ Maund**	**662,400**	**652,320**
E. Net income		**489,300**	**484,320**
F. Total cost: Net income Cost Benefit Ratio		**173,100: 489,300 1.00:2.83**	**168,000: 484,320 1.00:2.88**

Table 1 describes the results for the cost-benefit ratio of the two treatments i.e., conventional farmer and IPM based on the actual expenses and revenue basis. It was observed that the cost of production that includes land preparation, cost of seed, labor cost for transplanting, inter-culturing, irrigation, picking of tomato fruits, along with packaging charges of plastic bags, transportation and miscellaneous were same for both conventional and IPM treatments i.e., Rs. 160,000/= per acre. However, there was a difference in the cost of protection against *T. absoluta* that required two sprays of Belt in conventional farmer's treatment (Rs. 8,000/=), whereas in IPM treatment cost of protection were Rs. 13,100/= that consists of spray of Neem extracts, cost of light and pheromone traps, and sowing of push-pull crops. Thus, overall cost of production and protection in conventional farmers and IPM treatments were estimated as Rs. 168,000/= and Rs. 173,100/=, respectively. Moreover, the total income generated from the conventional farmers (724.80 maunds per acre) and IPM (736.00 maunds per acre) treatments was Rs. 652,320/= and Rs. 662,400/=, respectively, which resulted in net profit of Rs. 484,320/= and Rs. 489,300/= for the two treatments, respectively. As a result, the cost-benefit ratio for almost same for the conventional farmers (1.00:2.88) and IPM (1.00:2.83) treatments.

Discussion

Integrated Pest Management (IPM) emphasis on the use of a healthy crop environment, incorporating all the possible measures to keep the pest population below threshold level with minimum use of synthetic chemicals, hence less risk to humans and their environment (FAO and WHO, 2014). Thus, IPM approach has also been practiced against *T. absoluta* in many countries of the world, mainly because it has developed resistance against many widely used synthetic insecticides (Mohamadi *et al*., 2017). In continuity of the same, our evaluated IPM model that comprised the use of light and pheromone traps monitoring and mass trapping of *T. absoluta* along with plantation of push (spearmint) and pull (garden cress) plants mostly control the development of *T. absoluta* infestation on tomato leaves and fruits; thus, only a single spray of Neem extracts was required to bring its infestation below threshold. It was observed in the study that pheromone and light traps not only help to monitor *T. absoluta* adults' populations, but also reduce its infestation by reducing the future progeny, whereas push and pull plants drive the moths away from the IPM treatment plots.

Many previous studies also evaluated variable IPM models that have successfully controlled the infestation of *T. absoluta* in tomatoes. Giorgini *et al*. (2019) integrated various bio-control agents such as egg parasitoids and mirid bugs, *Bt*- insecticides, selected synthetic chemical insecticides, and sex pheromone in the greenhouse tomatoes, and found it very effective to control *T. absoluta* infestation better than control treatments. Another study using the integrated approach of using eight traps per feddan of sex pheromones for mass trapping of *T. absoluta*, along with twice sequence application of Voliam flexi 40WG (Thiamethoxam 20% + Chlorantaniliprole 20%) and Dan top 50WG (Clothianidin) during vegetative growth, Diper DF 6.4WG (*Bacillus thuringiensis*) during fruiting stages, performed in reduced *T. absoluta* infestation than the sole use of synthetic pheromones (Taha *et al*., 2013). The same study also reported that the number of pesticide applications were significantly lower (11 sprays) in IPM treatment than the conventional farmer's treatment (16 sprays). Goda *et al*. (2015) experiments on integrated management of *T. absoluta* reported that the release of egg parasitoid (*Trichogrammatoidea bactrae*) along with mass trapping using pheromone traps (plot-B) was found best treatment in reducing its infestation, followed by application of Biotrine and Fytomax plus mass trapping treatment (plot-A), whereas control treatment with the use of synthetic insecticides was the least effective in controlling *T. absoluta* infestation. Moreover, plot-B also produced a higher yield with better cost benefit ration.

Buragohain *et al*. (2021) conducted multi-location IPM trials against *T. absoluta* that comprised of applications of microbial insecticides (*Bt*- var *kurstaki* and *Beauveria bassiana*), Neem products, and Chlorantraniliprole, a selected insecticide. The results were compared with farmer's practice to manage *T. absoluta* infestation using synthetic insecticides. It was also observed in that study that at all the locations, IPM package was found equally efficient in managing the infestation of *T. absoluta* on leaves and fruits as the same resulted in comparably higher yields in farmer's field plots at all the locations but the same were not significantly different from yield obtained in the IPM treatments of the respective locations. Thus, these findings support our results as the mean infestation tomato leaves were significantly higher in IPM, whereas fruits suffered significantly higher infestation in the farmer's adapted treatment. Accordingly, the comparatively higher yield in our study was obtained in IPM but the same was not significantly different from the yield of farmer's treatment. In the same study, significantly better returns (twice) based on the cost benefit ratio were reported in IPM treatment than conventional farmer's practice due to excessive spraying of synthetic insecticides, but in our study, there was slightly higher returns in farmer's treatment than IPM. The reason for such variation was mainly because Buragohain *et al*. (2021) included only the cost of insecticides in the calculation of cost benefit ratio between the two treatments, whereas we also included the cost of traps i.e., pheromone and light, cultivation of push-pull plants while calculating the ratio.

Another IPM model developed and used against *T. absoluta* in tomato cultivation in Sudan by Mahmoud *et al*. (2020) also supported our findings as following the suggested model, infestation of *T. absoluta* was reduced in the tomato that resulted in significantly lower yield losses than control treatment. The model suggested was comprised of use of two hymenopteran parasitoids and two predatory bugs to control *T. absoluta* larvae, use of pheromone traps and deployment of male lure Tuta optima ® in water traps from seedling till harvesting to capture adults moths to reduce their population and fruit infestation, application of Neem and Khilla leaves extracts to number of larvae per leaflet to reduce the infestation and augment tomato yield, whereas intercropping of Coriander and Fenugrik reduced *T. absoluta* infestation and enhance the quality and quantity of the yield (Mahmoud *et al*., 2020).

Although, no significant difference was recorded in the fruiting yield of IPM and conventional practices used in our study, and the same resulted in almost same cost benefit ratio between the two treatments, but it has been suggested that eco-friendly management tools that have been developed and used in various countries of the world could control it without disturbing the ecological world (Aynalem, 2018). Among the key components of IPM used against *T. absoluta* includes the use of cultural practices such as crop rotation, selective removal, and destruction of infested fruits (Korycinska and Moran, 2009; Han *et al*., 2014, 2016, 2019b; Biondi *et al*., 2018), use of parasitoids, predators, parasites, nematodes, and entomopathogens (Desneux *et al*., 2010, 2022; Ferracini *et al*., 2012; Urbaneja *et al*., 2012; Biondi *et al*., 2018), use of botanicals (Biondi *et al*., 2012a; Soares *et al*., 2019; Campolo *et al*., 2020; Mansour and Biondi, 2021), use of resistant tomato cultivars (Ahmed, 2007; Oliveira *et al*., 2012; Selale *et al*., 2017) and mating disruption and mass trapping (Roda *et al*., 2015; Abd El-Ghany *et al*., 2016; Cherif *et al*., 2018; Mansour *et al*., 2019; Mansour and Biondi, 2021) along with use of selective synthetic insecticides (Desneux *et al*., 2010, 2022). Thus, the adaptation of IPM strategies against key insect pests including *T. absoluta* could be advantageous to traditional farmer's practices which mainly rely on the use of synthetic chemicals in reducing the adverse effects of synthetic chemicals such as environmental pollution, hazards to humans, non-target organisms including natural enemies, phytotoxicity, and development of resistance among pest species (Aynalem, 2018; Buragohain *et al*., 2021; Desneux *et al*., 2022). Although, there is lack of evidence on the economic and health benefits of the adoption of IPM models, however among the little available evidence, Cuyno *et al*. (2001) reported additional income of 231 to 305 pesos per person when they adopted IPM practices in onion, whereas aggregate environmental benefits in the study were estimated at 150,000 US$ for the 4600 local residents. Midingoyi *et al*. (2019) also reported that when farmers adapted the IPM practices in their mango orchards, especially against fruit flies they get additional benefits in mango yield, net income, less insecticide usage, improved human health, and better environment. They also found that with the practice of multiple IPM models in mango orchards, growers generate improved economic, environmental, and human health benefits, hence emphasized for the use of multiple IPM models in their farming.

Considering the diversified advantages of IPM models, Sridhar *et al*. (2019) also conducted a series of experiments to suggest the integrated management model of *T. absoluta* in tomatoes. They found that Accession LA 1940 of *Solanum penellii* was resistant to *T. absoluta* infestation, whereas *B. thuringiensis, Metarhizium anisopliae, B. bassiana* and *M. rileyi*, the entomopathogens, and egg parasitoids (*T. chilonis, T. pretiosum,* and *T. bactrae*) were determined as its key natural enemies to keeps its population and infestation in check. Moreover, installation of yellow light traps and the application of Azadirachtin

5% EC were also found effective in reducing the infestation of *T. absoluta*, whereas among synthetic insecticides, Spinotram 12SC was found to be very effective. Hence, an integrated model of yellow light traps, *T. pretiosum,* and application of either azadirachtin or Spinotram could result in lower *T. absoluta* populations and infestation along with better tomato yields (Sridhar *et al.*, 2019).

Oke *et al.* (2020) also proposed an integrated management model according to agro-climatic conditions of tomato cultivation in Nigeria to control the infestation of *T. absoluta*. They reported that integration of setting water + light traps, hygiene, and six rotational applications of different insecticides with variable mode of actions i.e., Imidacloprid, Lambdacyhalothrin, Acetamiprid + Lambdacyhalothrin, and Novaluron+Bifenthrin resulted in a 57.52% reduction in total *T. absoluta* infestation, whereas the frequent application (up to ten sprays) of a systematic insecticide thiamethoxam within five weeks could not prove effective to reduce its infestation considerably.

Sex pheromones of *T. absoluta* has been included as an integral part of its integrated management because it has been effective for its management and mass trapping (Desneux *et al.*, 2022; Mangrio *et al.*, 2023). Besides, pheromone traps, golden colored traps used in the study were also found effective, not only in *T. absoluta* monitoring, but also help in reducing its infestation. The studies suggested that both light and pheromone traps are key in the monitoring seasonal activity of *T. absoluta* under field conditions in tomatoes (Salama *et al.*, 2015; Kadel *et al.*, 2018; Sridhar and Kumaran, 2018). Moreover, their combined use has resulted in better management of *T. absoluta* because moth adult males and females are attracted and captured, hence reducing the chances of the mating and future progeny (Cocco *et al.*, 2012; Castresana and Puhl, 2017). Thus, Bloem and Spaltenstein (2011) established a modified in which they added pheromone dispenser of *T. absoluta* in a light traps and as a result they captured significantly higher numbers of *T. absoluta* moths including the females. Therefore, results obtained in our study also highlighted the importance of both golden colored light and pheromone traps not only in monitoring the seasonal variation in *T. absoluta* population, but also as a key element in reducing its infestation in tomatoes.

Although, push and pull concept of management has yet not been exploited in *T. absoluta* management, but its importance has been accepted and tested against many insect pests, especially *Spodoptera frugiperda* (Khan *et al.*, 2010; Yeboah *et al.*, 2021; Sobhy *et al.*, 2022). Besides, *S. frugiperda*, push and pull strategy has been successfully used against *Bactrocera minax* (Cui *et al.*, 2022), *Frankliniella occidentalis* (Kim *et al.*, 2023), *Empoasca flavescens* F. (Niu *et al.*, 2022), brassica vegetable crops (da Silva *et al.*, 2022) and against fruit orchard pests (Byers and Levi-Zada, 2022). Accordingly, Giorgini *et al.* (2019) also suggested its use in the management of *T. absoluta*. Thus, it was observed that use of spearmint (push) and garden cress (pull) plants in tomatoes proved effective in diverting *T. absoluta* populations from the main crop, contributing in an integrative manner with other control measures to reduce *T. absoluta* infestation.

The Neem extracts used in our study was capable to reduce the infestation of *T. absoluta* as it has been suggested that azadirachtin obtained from Neem mainly effect through ingestion than contact, hence making it less toxic to natural enemies, hence is included as an essential component in IPM of many insect pests (Nisbet, 2000; Berxolli and Shahini, 2017). Studies also reported that the Neem extracts or products may have antifeedant, repellent, and toxic properties against the target pests, and the same may be responsible for reduction of *T. absoluta* infestation in this study after the application of Neem extracts (Cunha *et al.*, 2006; Abd El-Ghany *et al.*, 2018). It has also been observed that azadirachtin affects the larval development that resulted in enhanced mortality (Brunherotto *et al.*, 2010; Tome *et al.*, 2013; Shiberu and Getu, 2018).

Results of study also confirmed that adaptation of IPM practices against *T. absoluta* have a positive influence on the tomato fruit yield as comparatively higher but not significantly different yield was obtained in IPM treatment than conventional farmer's practices. As the results of our study suggested no significant difference was observed in overall cost: benefit ratio between the two practices in managing *T. absoluta*. The results of Goda *et al.* (2015) partially supported our findings as they also recorded higher tomato yield with better returns by adopting integrated approach to manage *T. absoluta* in tomatoes than the conventional practices. The findings of Buragohain *et al.* (2021) did not validate findings of this research because they observed higher benefit (up to two times higher) when adapting the IPM approach for the management of *T. absoluta* than conventional farmer practice.

It is clear from the above discussion including this research that various integrated management tools have a significant role in reducing the *T. absoluta* infestation in tomatoes, even when applied individually or in combination. However, there is a lot of potential to explore different combinations of available management tools against *T. absoluta* that not only help to reduce its infestation on tomatoes to get better quality tomato fruit yield in comparison to conventional farmer's practices. The adaptation of such IPM models could also help indirectly to conserve and improve the functionality of ecosystem by conserving the soil, increasing nutrients availability, and enhances biodiversity (Cuyno *et al*., 2001; Midingoyi *et al*., 2019). Therefore, it is suggested that an appropriate integrated approach based on all the available tools depending on the particular growing conditions of the area should be followed to get better *T. absoluta* management with higher yields (Muniappan, 2015; Desneux *et al*., 2022). However, there are still many other options that should be explored in IPM of *T. absoluta* as the importance of crop rotation practices using non-solanaceous crops with tomato has been highlighted as it has the potential to break the continuity of *T. absoluta* populations (Rwomushana *et al*., 2019; Desneux *et al*., 2022). Moreover, the removal of alternate hosts of *T. absoluta*, especially wild relatives of tomato, can also be helpful in reducing its infestation, because it can limit the movement and development of *T. absoluta* population to the next cropping season (Rwomushana *et al*., 2019). It has also been reported that adequate fertilization can enhance the strength of tomato plants that can be able to affect the biological parameters i.e., developmental time, fecundity, and oviposition period of *T. absoluta* (Mohamadi *et al*., 2017).

Conclusion

The adaptation of IPM practices i.e., golden light and pheromone traps, cultivation of push (spearmint) and pull (garden cress) plants, and application of Neem extracts at threshold levels, proved effective in reducing the *T. absoluta* infestation in tomato. Overall, comparatively higher infestation of *T. absoluta* on leaves was recorded in IPM than conventional farmer's treatment, whereas fruits significantly much lower infestation in IPM. Thus, the tomato yield observed in IPM treatment was comparatively higher than conventional farmer treatment, resulting in no significant difference in cost: Benefit ratio between the two treatments.

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Novelty Statement

Recent invasion of *Tuta absoluta* necessitates its timely management with less hazardous control measures. Thus, the results obtained confirmed that integrated approach using pheromone and golden colored light traps, spearmint as push crop, garden cress as pull plant, and spray of neem, when required as botanical insecticides keep *T. absoluta* population below threshold levels, hence ensure less dependence on the synthetic insecticides.

Author's Contribution

Ghulam Qader Mangrio, Arfan Ahmed Gilal and Lubna Bashir Rajput: Designed the study.
Ghulam Qader Mangrio and Abdul Hayee Gabol: Conducted the experiments.
Jamal-U-Ddin Hajano and Abdul Rauf Bhatti: Analyzed data.
Zakia Panhwar, Muhammad Ishaque Mastoi and Arfan Ahmed Gilal: Wrote and finalized the manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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