

Research Article

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

Ghulam Qader Mangrio¹, Arfan Ahmed Gilal^{1*}, Lubna Bashir Rajput¹, Jamal-U-Ddin Hajano², Abdul Rauf Bhatti³, Muhammad Ishaque Mastoi³, Zakia Panhwar⁴ and Abdul Hayee Gabol¹

¹Department of Entomology, Faculty of Crop Protection, Sindh Agriculture University, Tandojam, Pakistan; ²Department of Plant Pathology, Faculty of Crop Protection, Sindh Agriculture University, Tandojam, Pakistan; ³National Insect Museum, National Agricultural Research Council, Islamabad, Pakistan; ⁴Southern Zone, Agricultural Research Center, Pakistan Agricultural Research Council, Karachi, Pakistan.

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.

Received | August 05, 2024; **Accepted** | November 09, 2025; **Published** | December 26, 2024

***Correspondence** | Arfan Ahmed Gilal, Department of Entomology, Faculty of Crop Protection, Sindh Agriculture University, Tandojam, Pakistan; **Email:** aagilal@sau.edu.pk

Citation | Mangrio, G.Q., A.A. Gilal, L.B. Rajput, J-U-D. Hajano, A.R. Bhatti, M.I. Mastoi, Z. Panhwar and A.H. Gabol. 2024. Integrated pest management of *Tuta absoluta* (Lepidoptera: Gelechiidae) in tomato field. *Pakistan Journal of Agricultural Research*, 37(4): 426-437.

DOI | <https://dx.doi.org/10.17582/journal.pjar/2024/37.4.426.437>

Keywords | Attractant, Cost-benefit, Good agricultural practices, Infestation, Leafminer, Repellent



Copyright: 2024 by the authors. Licensee ResearchersLinks Ltd, England, UK.

This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

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 inside 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 ft². 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 $0.90 \pm 0.14\%$, 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 $20.25 \pm 2.15\%$ 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 $5.35 \pm 0.57\%$ within two weeks of the application, however, it then gradually increased to reach up to $15.15 \pm 1.35\%$ 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 $3.13 \pm 0.40\%$ at the end of final harvesting during week twenty-four (Figure 1).

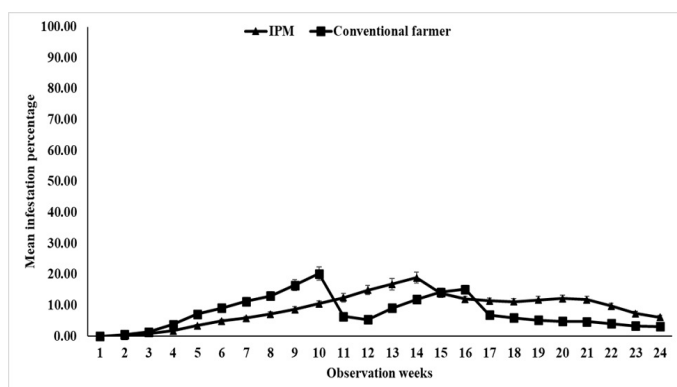


Figure 1: *Impact of integrated and conventional farmer's practices on the mean infestation percentage of Tuta absoluta on tomato leaves.*

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 $18.93 \pm 1.84\%$. After the application of Neem extracts, a sharp decline in *T. absoluta* infestation on tomato leaves was recorded that reached to $13.85 \pm 1.35\%$ during week fifteen and the same decreased gradually towards final harvesting of tomatoes during the week twenty-four ($6.10 \pm 0.61\%$) (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 $0.18 \pm 0.07\%$, 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 ($12.75 \pm 1.08\%$) 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 ($4.75 \pm 0.49\%$) and the same gradually declined towards the final harvesting of tomato during the week twenty-four ($2.40 \pm 0.35\%$) (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 $8.05 \pm 0.87\%$ 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.

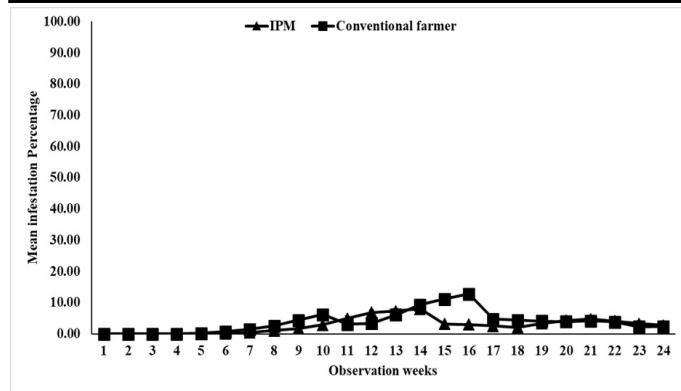


Figure 2: Impact of integrated and conventional farmer's practices on the mean infestation percentage of *Tuta absoluta* on tomato fruits.

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 ($8.91 \pm 0.06\%$) than conventional farmers treatment ($7.64 \pm 0.25\%$), tomato fruits suffered significantly ($F = 51.42$, $P < 0.001$) lower infestation in IPM treatment ($2.77 \pm 0.12\%$) than the conventional farmers treatment ($3.79 \pm 0.15\%$).

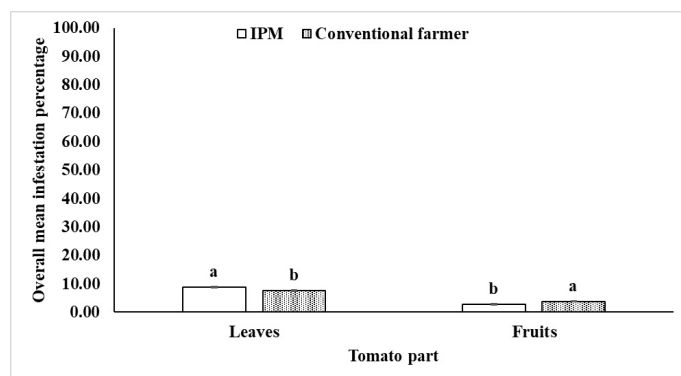


Figure 3: Impact of integrated and conventional farmer's practices on overall mean infestation percentage of *Tuta absoluta* on tomato leaves and fruits.

*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).

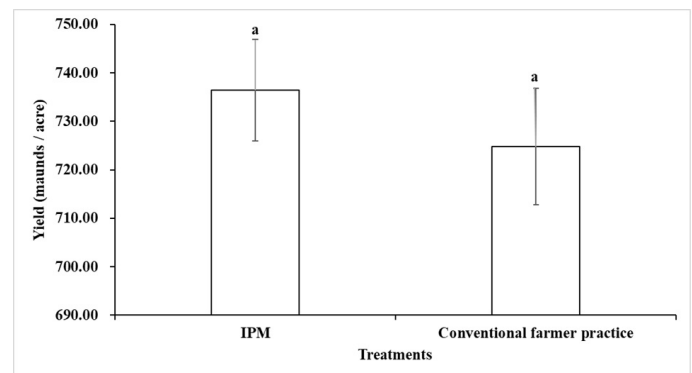


Figure 4: Impact of integrated and conventional farmer's practices against *Tuta absoluta* on tomato yield.

*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.
Land preparation	15,000	15,000
Tomato Seed	20,000	20,000
Transplanting	2,000	2,000
Inter-culturing	8,000	8,000
Fertilizer	45,000	45,000
Weedicides	0	0
Irrigation labor charges	5,000	5,000
Picking charges	30,000	30,000
Packing charges (plastic)	5,000	5,000
Other expenses (transportation)	20,000	20,000
Miscellaneous	10,000	10,000
Total of (A)	160,000	160,000
B. Cost of protection		
Neem extracts (labor charges)	2,000	2,000
Light traps	1,600	1,600
Pheromone traps	8,000	8,000
Push/ Pull crops	1500	1500
Chemical control- belt (2 sprays) + labor charges	4000	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
E. Net income	489,300	484,320
F. Total cost: Net income	173,100:	168,000:
Cost Benefit Ratio	489,300	484,320
	1.00:2.83	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% + Chlorantraniliprole 20%) and Dan top 50WG (Clothianidin) during vegetative growth, Dipe 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 Fenugreek 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, Cuyano *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 keep 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, Lambda cyhalothrin, Acetamiprid + Lambda cyhalothrin, 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; Bexxolli 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 (Cuyano *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.

Acknowledgments

The research is part of ALP (CS-551) Funded project "Development of integrated pest management strategies to combat Invasive Tomato Leafminer (*Tuta absoluta*) in Pakistan" implemented by teams of National Insect Museum.

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.

References

- Abd-El-Ghany, A., M. Nesreen, A.S. Abdel-Razek, I. Ebadah and Y.A. Mahmoud. 2016. Evaluation of some microbial agents, natural and chemical compounds for controlling tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). J. Plant Prot. Res., 56(4): 372–379. <https://doi.org/10.1515/>

jppr-2016-0055

- Abd-El-Ghany, N.M., A.S. Abdel-Razek, K. Djelouah and A. Moussa. 2018. Efficacy of bio-rational insecticides against *Tuta absoluta* (Meyrick)(Lepidoptera: Gelechiidae) on tomatoes. Biosci. Res., 15(1): 28-40.
- Abdelmaksoud, N.M., N.F. Abdel-Aziz, E.A. Sammour, E.A.E.M. Agamy, A.M. El-Bakry and M.A.H. Kandil. 2020. Influence of insect traps and insecticides sequential application as a tactic for management of tomato leaf miner, *Tuta absoluta* (Meyrick), (Lepidoptera: Gelechiidae). Bull. Nat. Res. Cent., 44: 1-9. <https://doi.org/10.1186/s42269-020-00376-y>
- Ahmed, A.E.M.B., 2007. Effect of UV-light, sun-light and field conditions on the stability of neem seed oil extract. M.Sc. thesis, University of Khartoum, Sudan, pp. 78. Available at: <http://khartoumspace.uofk.edu/handle/123456789/11983> (accessed 28 August 2023).
- Aynalem, B., 2018. Tomato leafminer [(*Tuta absoluta* Meyrick) (Lepidoptera :Gelechiidae)] and its current ecofriendly management strategies : A review. J. Agric. Biotech. Sustain. Dev., 10(2): 11-24. <https://doi.org/10.5897/JABSD2018.0306>
- Berxolli, A. and S. Shahini. 2017. Azadirachtin, a useful alternative for controlling *Tuta absoluta* (Myerick). Eur. J. Phys. Agric. Sci., 5(2): 40-45. <https://doi.org/10.18638/quaesti.2017.5.1.320>
- Biondi, A., N. Desneux, G. Siscaro and L. Zappala. 2012a. Using organic-certified rather than synthetic pesticides may not be safer for biological control agents: Selectivity and side effects of 14 pesticides on the predator *Orius laevigatus*. Chemosphere, 87(7): 803-812. <https://doi.org/10.1016/j.chemosphere.2011.12.082>
- Biondi, A., R.N.C. Guedes, F.H. Wan and N. Desneux. 2018. Ecology, worldwide spread, and management of the invasive South American tomato pinworm, *Tuta absoluta*: Past, present, and future. Annu. Rev. Entomol., 63: 239-258. <https://doi.org/10.1146/annurev-ento-031616-034933>
- Bloem, S. and E. Spaltenstein. 2011. New pest response guidelines: Tomato leaf miner (*Tuta absoluta*). USDA. Emergency and domestic program, Riverdale, Maryland. https://www.aphis.usda.gov/import_export/plants/manuals/emergency/downloads/Tuta-absoluta.pdf
- Brunherotto, R., J.D. Vendramim and M.A.D.G. Oriani. 2010. Effects of tomato genotypes and aqueous extracts of *Melia azedarach* leaves and *Azadirachta indica* seeds on *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). Neotrop. Entomol., 39: 784-791. <https://doi.org/10.1590/S1519-566X2010000500018>
- Buragohain, P., D.K. Saikia, P. Sotelo-Cardona and R. Srinivasan. 2021. Development and validation of an integrated pest management strategy against the invasive South American tomato leaf miner, *Tuta absoluta* in South India. Crop Prot., 139: 105348. <https://doi.org/10.1016/j.cropro.2020.105348>
- Byers, J.A. and A. Levi-Zada. 2022. Modelling push-pull management of pest insects using repellents and attractive traps in fruit tree orchards. Pest Manage. Sci., 78(8): 3630-3637. <https://doi.org/10.1002/ps.7005>
- Campolo, O., I. Puglisi, R.N. Barbagallo, A. Cherif and M. Ricupero. 2020. Side effects of two citrus essential oil formulations on a generalist insect predator, plant and soil enzymatic activities. Chemosphere, 257: 127252. <https://doi.org/10.1016/j.chemosphere.2020.127252>
- Castresana, J. and L. Puhl. 2017. Comparative study among a variety of solar-powered LED traps to capture tomato leafminers *Tuta absoluta* adults by mass trapping in tomato greenhouses in the Province of Entre Ríos, Argentina. IDESIA, 35(4): 87-95. <https://doi.org/10.4067/S0718-34292017000400087>
- Cherif, A., K. Harbaoui, L. Zappala and K. Grissa-Lebdi. 2018. Efficacy of mass trapping and insecticides to control *Tuta absoluta* in Tunisia. J. Plant Dis. Prot., 125: 51-61. <https://doi.org/10.1007/s41348-017-0140-6>
- Cocco, A., S. Deliperi and G. Delrio. 2012. Potential of mass trapping for *Tuta absoluta* management in greenhouse tomato crops using light and pheromone traps. Int. Org. Biol. Integr. Cont., West Palaearctic Reg. Sect. Bull., 80: 319-324.
- Cui, Z., P. Si, L. Liu, S. Chen, Y. Wang, X. Li and Q. Zhou. 2022. Push-pull strategy for integrated control of *Bactrocera minax* (Diptera, Tephritidae) based on olfaction and vision. J. Appl. Entomol., 146: 1243-1251. <https://doi.org/10.1111/jen.13067>
- Cunha, U.S.D., J.D. Vendramim, W.C. Rocha and P.C. Vieira. 2006. Frações de *Trichilia*

- pallens com atividade inseticida sobre *Tuta absoluta*. Pesquisa Agropecuária Brasileira, 41: 1579-1585. <https://doi.org/10.1590/S0100-204X2006001100002>
- Cuyno, L.C., G.W. Norton and A. Rola. 2001. Economic analysis of environmental benefits of integrated pest management: A Philippine case study. Agric. Econ., 25(2-3): 227-233. <https://doi.org/10.1111/j.1574-0862.2001.tb00203.x>
- da Silva, V.F., A. dos Santos, L.C.P. Silveira, V.B. Tomazella and R.M. Ferraz. 2022. Push-pull cropping system reduces pests and promotes the abundance and richness of natural enemies in brassica vegetable crops. Biol. Cont., 166: 104-832. <https://doi.org/10.1016/j.biocontrol.2021.104832>
- Desneux, N., A. Decourtye and J.M. Delpuech. 2007. The sublethal effects of pesticides on beneficial arthropods. Annu. Rev. Entomol., 52: 81-106. <https://doi.org/10.1146/annurev.ento.52.110405.091440>
- Desneux, N., E. Wajnberg, K.A. Wyckhuys, G. Burgio, S. Arpaia, C.A. Narváez-Vasquez and A. Urbaneja. 2010. Biological invasion of European tomato crops by *Tuta absoluta*: ecology, geographic expansion and prospects for biological control. J. Pest Sci., 83: 197-215. <https://doi.org/10.1007/s10340-010-0321-6>
- Desneux, N., P. Han, R. Mansour, J. Arnó, T. Brévault, M.R. Campos and A. Biondi. 2022. Integrated pest management of *Tuta absoluta*: practical implementations across different world regions. J. Pest Sci., 95: 17-39. <https://doi.org/10.1007/s10340-021-01442-8>
- FAO and WHO, 2014. The international code of conduct on pesticide management. Rome.
- Ferracini, C., B.L. Ingegno, P. Navone, E. Ferrari, M. Mosti, L. Tavella and A. Alma. 2012. Adaptation of indigenous larval parasitoids to *Tuta absoluta* (Lepidoptera: Gelechiidae) in Italy. J. Econ. Entomol., 105(4): 1311-1319. <https://doi.org/10.1603/EC11394>
- Gabol, A.H., A.A. Gilal, L.B. Rajput and G.Q. Mangrio. 2023. Distribution and damage potentials of tomato leafminer, *Tuta absoluta* (Lepidoptera: Gelechiidae) Sindh, Pakistan. Proc. Pak. Acad. Sci. Life Environ. Sci., 60(2): 283-291. [https://doi.org/10.53560/PPASB\(60-2\)758](https://doi.org/10.53560/PPASB(60-2)758)
- Giorgini, M., E. Guerrieri, P. Cascone and L. Gontijo. 2019. Current strategies and future outlook for managing the Neotropical tomato pest *Tuta absoluta* (Meyrick) in the Mediterranean Basin. Neotrop. Entomol., 48: 1-17. <https://doi.org/10.1007/s13744-018-0636-1>
- Goda, N.F., A.H. El-Heneidy, K. Djelouah and N. Hassan. 2015. Integrated pest management of the tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in tomato fields in Egypt. Egypt. J. Biol. Pest Cont., 25(3): 655-661.
- Grant, C., R. Jacobson, A. Ilias, M. Berger, E. Vasakis, P. Bielza, C. T. Zimmer, M. S. Williamson, R. H. French-Constant, J. Vontas, E. Roditakis and C. Bass. 2019. The evolution of multiple-insecticide resistance in UK populations of tomato leaf miner, *Tuta absoluta*. Pest Manage. Sci., 75(8): 2079-2085. <https://doi.org/10.1002/ps.5381>
- Han, P., Y. Bayram, L. Shaltiel-Harpaz, F. Sohrabi, A. Saji, U.T. Esenali and N. Desneux. 2019a. *Tuta absoluta* continues to disperse in Asia: Damage, ongoing management and future challenges. J. Pest Sci., 92: 1317-1327. <https://doi.org/10.1007/s10340-018-1062-1>
- Han, P., N. Desneux, C. Becker, R. Larbat, J. Le Bot, S. Adamowicz and A.V. Lavoie. 2019b. Bottom-up effects of irrigation, fertilization and plant resistance on *Tuta absoluta*: Implications for integrated pest management. J. Pest Sci., 92: 1359-1370. <https://doi.org/10.1007/s10340-018-1066-x>
- Han, P., A.V. Lavoie, J. Le Bot, E. Amiens-Desneux and N. Desneux. 2014. Nitrogen and water availability to tomato plants triggers bottom-up effects on the leafminer *Tuta absoluta*. Sci. Rep., 4(1): 4455. <https://doi.org/10.1038/srep04455>
- Han, P., N. Desneux, T. Michel, J. Le Bot, A. Seassau, E. Wajnberg, E. Amiens-Desneux and A.V. Lavoie. 2016. Does plant cultivar difference modify the bottom-up effects of resource limitation on plant-insect herbivore interactions? J. Chem. Ecol., 42(12): 1293-1303. <https://doi.org/10.1007/s10886-016-0795-7>
- Ishtiaq, M., M. Sadique, N. Faried, U. Naeem-Ullah and M.A. Hamza. 2020. First record of tomato leafminer, *Tuta absoluta* (Meyrick 1917) (Lepidoptera: Gelechiidae) from southern part of Punjab, Pakistan. J. Anim. Plant Sci., 30(6): 1604-1611. <https://doi.org/10.36899/>

JAPS.2020.6.0181

- Jallow, M.F., A.A. Dahab, M.S. Albaho, V.Y. Devi, J. Jacob and O. Al-Saeed. 2020. Efficacy of mating disruption compared with chemical insecticides for controlling *Tuta absoluta* (Lepidoptera: Gelechiidae) in Kuwait. Appl. Entomol. Zool., 55: 213-221. <https://doi.org/10.1007/s13355-020-00673-y>
- Kadel, J., L.P. Sah, M. Devkota, L.A. Colavito, G. Norton, E.G. Rajotte and R. Muniappan. 2018. Effectiveness of different types of traps for management of *Tuta absoluta* in Nepal. J. Plant Prot. Soc., 5: 166-174. <https://doi.org/10.3126/jpps.v5i0.47128>
- Khan, Z.R., C.A. Midega, T.J. Bruce, A.M. Hooper and J.A. Pickett. 2010. Exploiting phytochemicals for developing a 'push-pull' crop protection strategy for cereal farmers in Africa. J. Exp. Bot., 61(15): 4185-4196. <https://doi.org/10.1093/jxb/erq229>
- Kim, C.Y., F. Khan and Y. Kim. 2023. A push-pull strategy to control the western flower thrips, *Frankliniella occidentalis*, using alarm and aggregation pheromones. PLoS One, 18(2): e0279646. <https://doi.org/10.1371/journal.pone.0279646>
- Korycinska, A. and H. Moran. 2009. South American tomato moth (*Tuta absoluta*): plant pest factsheet. Publisher, Department for Environment, Food and Rural Affairs, Sand Hutton, York, UK, FERA, pp. 4.
- Mahmoud, M.E., E.S. Mohammed, S.A. Mohamed, F.M. Khamis and S. Ekesi. 2020. Development and implementation of a sustainable IPM and surveillance program for the invasive tomato leafminer, *Tuta absoluta* (Meyrick) in Sudan. Athens J. Sci., 7: 159-174. <https://doi.org/10.30958/ajs.7-3-3>
- Mangrio, G.Q., A.A. Gilal, L.B. Rajput and A.H. Gabol. 2023. Performance of pheromone and light traps in monitoring and management of tomato leafminer, *Tuta absoluta* (Lepidoptera: Gelechiidae). J. Saudi Soc. Agric. Sci., <https://doi.org/10.1016/j.jssas.2023.01.004>
- Mansour, R., A. Cherif, S. Attia-Barhoumi, L. Zappalà and K. Grissa-Lebdi. 2019. *Tuta absoluta* in Tunisia: Ten years of invasion and pest management. Phytoparasitica, 47: 461-474. <https://doi.org/10.1007/s12600-019-00748-9>
- Mansour, R. and A. Biondi. 2021. Releasing natural enemies and applying microbial and botanical pesticides for managing *Tuta absoluta* in the MENA region. Phytoparasitica, 49(2): 179-194. <https://doi.org/10.1007/s12600-020-00849-w>
- Midingoyi, S.K.G., M. Kassie, B. Muriithi, G. Diiro and S. Ekesi. 2019. Do farmers and the environment benefit from adopting integrated pest management practices? Evidence from Kenya. J. Agric. Econ., 70(2): 452-470. <https://doi.org/10.1111/1477-9552.12306>
- Mohamadi, P., J. Razmjou, B. Naseri and M. Hassanpour. 2017. Population growth parameters of *Tuta absoluta* (Lepidoptera: Gelechiidae) on tomato plants using organic substrate and biofertilizers. J. Ins. Sci., 17(2): 36. <https://doi.org/10.1093/jisesa/iex011>
- Muniappan, R., 2015. *Tuta absoluta*: The tomato leafminer. Collaborative Research on Integrated Pest Management. United State of America. <https://ipmil.cired.vt.edu/wp-content/uploads/2014/09/Tuta-absoluta-Presentation-Muniappan-Nov.26.2013.pdf>
- Nisbet, A.J., 2000. Azadirachtin from the neem tree *Azadirachta indica*: Its action against insects. Anais Soc. Ent. Brasil., 29: 615-632. <https://doi.org/10.1590/S0301-80592000000400001>
- Niu, Y., S. Han, Z. Wu, C. Pan, M. Wang, Y. Tang and B. Han. 2022. A push-pull strategy for controlling the tea green leafhopper (*Empoasca flavescens* F.) using semiochemicals from *Tagetes erecta* and *Flemingia macrophylla*. Pest Manage. Sci., 78(6): 2161-2172. <https://doi.org/10.1002/ps.6840>
- Oke, O.A., R.O. Kolawole, O.A. Akinsola, L.O. Olajide-Taiwo, A.A. Oladigbolu and E.O. Ajayi. 2020. The first effort at adopting integrated Pest management IPM to contain the infestation of the *Tuta absoluta* in Nigeria. Sust. Manage. Inv. Pests Afr., pp. 57-64. https://doi.org/10.1007/978-3-030-41083-4_5
- Oliveira, C.M.D., V.C.D. Andrade Júnior, W.R. Maluf, I.P. Neiva and G.M. Maciel. 2012. Resistance of tomato strains to the moth *Tuta absoluta* imparted by allelochemicals and trichome density. Sci. Agric. Tech., 36(1): 45-52. <https://doi.org/10.1590/S1413-70542012000100006>
- Roda, A.L., J. Brambila, J. Barria, X. Euceda and C. Korytkowski. 2015. Efficiency of trapping systems for detecting *Tuta absoluta*

- (Lepidoptera: Gelechiidae). J. Econ. Entomol., 108(6): 2648-2654. <https://doi.org/10.1093/jee/tov248>
- Rwomushana, I., T. Beale, G. Chipabika, R. Day, P. Gonzalez-Moreno, J. Lamontagne-Godwin and J. Tambo. 2019. Tomato leafminer (*Tuta absoluta*): impacts and coping strategies for Africa. *Tomato leafminer (Tuta absoluta): Impacts and coping strategies for Africa*. CABI Working Paper 12: 56.
- Sadique, M., M. Ishtiaq, U. Naeem-Ullah and N. Faried. 2022. Spatio-temporal distribution of *Tuta absoluta* (Meyrick 1917)(Lepidoptera: Gelechiidae) from Pakistan. Int. J. Trop. Ins. Sci., 42(4): 3023-3032. <https://doi.org/10.1007/s42690-022-00837-z>
- Salama, H.S.A.E.R., I.A.K. Ismail, M. Fouda, I. Ebadah and I. Shehata. 2015. Some ecological and behavioral aspects of the tomato leaf miner *Tuta absoluta* (Meyrick)(Lepidoptera: Gelechiidae). Ecol. Balk., 7(2): 35-44.
- Selale, H., F. Dağlı, N. Mutlu, S. Doğanlar and A. Frary. 2017. Cry1Ac-mediated resistance to tomato leaf miner (*Tuta absoluta*) in tomato. Plant Cell, Tissue and Organ Culture, 131: 65-73. <https://doi.org/10.1007/s11240-017-1262-z>
- Shahini, S., A. Bërxolli and F. Kokojka. 2021. Effectiveness of bio-insecticides and mass trapping based on population fluctuations for controlling *Tuta absoluta* under greenhouse conditions in Albania. Heliyon, 7(1): e05753. <https://doi.org/10.1016/j.heliyon.2020.e05753>
- Shiberu, T. and E. Getu. 2018. Population dynamics study of *T. absoluta* in western Shewa of central Ethiopia. Adv. Crop Sci. Technol., 6(3): 1-8. <https://doi.org/10.4172/2329-8863.1000361>
- Soares, M.A., M.R. Campos, L.C. Passos, G.A. Carvalho, M.M. Haro, A.V. Lavoire and N. Desneux. 2019. Botanical insecticide and natural enemies: A potential combination for pest management against *Tuta absoluta*. J. Pest Sci., 92: 433-1443. <https://doi.org/10.1007/s10340-018-01074-5>
- Sobhy, I.S., A. Tamiru, X. Chiriboga Morales, D. Nyagol, D. Cheruiyot, F. Chidawanyika and Z.R. Khan. 2022. Bioactive volatiles from push-pull companion crops repel fall armyworm and attract its parasitoids. Front. Eco. Evol., 10: 883020. <https://doi.org/10.3389/fevo.2022.883020>
- Sridhar, V., and G.S. Kumaran. 2018. Light trap, an effective component of integrated management of *Tuta absoluta* (Lepidoptera: Gelechiidae) on tomato. J. Hortic. Sci., 13(1): 126-128. <https://doi.org/10.24154/jhs.v13i1.59>
- Sridhar, V., S.O. Naik, K.S. Nitin, R. Asokan, P. Swathi and H. Gadad. 2019. Efficacy of integrated pest management tools evaluated against *Tuta absoluta* (Meyrick) on tomato in India. J. Biol. Cont., 33(3): 264-270. <https://doi.org/10.18311/jbc/2019/23254>
- Taha, A.M., A.F.E. Afsah and F.H. Fargalla. 2013. Evaluation of the effect of integrated control of tomato leafminer *Tuta absoluta* with sex pheromone and insecticides. Nat. Sci., 11(7): 26-29.
- Tarusikirwa, V.L., H. Machekano, R. Mutamiswa, F. Chidawanyika and C. Nyamukondiwa. 2020. *Tuta absoluta* (Meyrick)(Lepidoptera: Gelechiidae) on the “offensive” in Africa: Prospects for integrated management initiatives. Insects, 11(11): 764. <https://doi.org/10.3390/insects11110764>
- Tomé, H.V.V., J.C. Martins, A.S. Corrêa, T.V.S. Galdino, M.C. Picanço and R.N.C. Guedes. 2013. Azadirachtin avoidance by larvae and adult females of the tomato leafminer *Tuta absoluta*. Crop Prot., 46: 63-69. <https://doi.org/10.1016/j.cropro.2012.12.021>
- Urbaneja, A., J. González- Cabrera, J. Arno and R. Gabarra. 2012. Prospects for the biological control of *Tuta absoluta* in tomatoes of the Mediterranean basin. Pest Manage. Sci., 68(9): 1215-1222. <https://doi.org/10.1002/ps.3344>
- Yeboah, S., S.A. Ennin, A. Ibrahim, P. Oteng-Darko, D. Mutyambai, Z.R., Khan and S. Niassy. 2021. Effect of spatial arrangement of push-pull companion plants on fall armyworm control and agronomic performance of two maize varieties in Ghana. Crop Prot., 145: 105-612. <https://doi.org/10.1016/j.cropro.2021.105612>