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Complementary biological management tactics: Parasitoid, sex pheromone and bio-agents against tomato borer, *Tuta absoluta* on tomato crop

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Abstract
Tomato borer, *Tuta absoluta* is a polyphytophagous species with highly reproductive potential and development on numerous cultivations, mainly belonging to Solanaceae crops, especially to tomato crop, *Lycopersicon esculentum.* It caused serious damages and yield losses of tomato crops due leaf mines and fruit infestations reach to 100% yield loss in tomato crops in both open-field and greenhouse conditions. Therefore, this study was carried out for assessing some biological control tactics using parasitoid, sex pheromone and bio-products against this pest on tomato crop. The obtained results showed that the releasing of 60 cards of *Trichogramma euproctidis* /feddan differed significantly comparing to the other rates of *Trichogramma* in dead larvae numbers of *T. absoluta*. So that, the releasing of 60 cards of *Tr. euproctidis* /feddan is the best rate that had been recorded by increasing the reduction of *T. absoluta* eggs and larvae than other treatments. The obtained data indicated that Tuta 100N baited with3 mg/ dispenser of (E,Z,Z) -3,8,11-Tetradecatrienyl acetate caught relatively high numbers of males than other investigated sexual pheromone traps. Additionally, the attractiveness longevity for the tested commercial sexual pheromone lures was powerful up to 30 days. In IPM program (treated field), the resulted a decreasing of tomato borer, *T. absoluta* mines according to reduce the mean numbers of larvae/ leaf through summer season, 2023. Abundance of *T. absoluta* eggs, larvae, mines and moths remained low populations in treated program (IPM tactics) than control field throughout summer season, 2023. Three peaks were noticed in control plot while two peaks were recorded in the treated field. Accordingly, this work was conducted by using of biocontrol agents including orange oil (d-Limonene), a mixture of *Capsicum oleoresin* extract +garlic oil+ canola oil, a mixture of citronella oil + jasmine oil + mineral oil, *Bacillus thuringiensis* subsp. Aizawai and azadirachtin helps in reducing *T. absoluta* infestations, thus it was essential in our study to explore the efficiency of a combination between some parasitoids and using of sexual-pheromone traps altogether to put the most suitable elements in tomato borer management plan.

Keywords: Biological control, plant extract, sex pheromone, tomato borer, *Trichogramma euproctidis*, *Tuta absoluta*

Introduction

Tomato, *Lycopersicon esculentum* is one of the most significant vegetable crops in the world and Mediterranean countries especially in Esgypt (Hassan, *et al*., 2017) [3]. The tomato production in Egypt is estimated to 6275443.91 tons from an area harvest of 143618 ha in 2022 (FAO, 2022). In Egypt, tomato is cultivated in opened fields and under both greenhouses and tunnels, it provides a good vegetable crop for investment income to farmers. Tomato borer, *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae) is devastated insect pest native from South America, that has been introduced accidentally into Egypt in 2009 (Urbaneja *et al*., 2009 and Hassan, 2015) [46, 3]. Tomato borer is a polyphytophagous species with highly reproductive potential and development on numerous cultivations, mainly belonging to Solanaceae crops (Hassan, 2015) [3]. In 2009, it was observed in Marsa Matrouh Governorate in Egypt and subsequently rapidly spread in all Egyptian regions with different its infestation rates (Moussa *et al*., 2013) [45]. Since the initial observation, this pest caused serious damages in tomato cultivations (Mohamed *et al*., 2012) [32], and it is currently considered a main key agricultural devastation to tomato production. The caterpillars of this pest feed on the leaf mesophyll caused leaf mines and also damage tomato stem and fruit. Really, This lepidopteran pest is perform a responsible of extensive injurious and yield losses of tomato crops, mainly due to causing leaf mines and fruit infestations. It can be caused serious damages reach to 100% yield loss in tomato crops in both open-field and greenhouse conditions (Gonring *et al*., 2020) [21].

The reliability of *T. absoluta* management undertook by employing several chemical insecticides on tomato crops (Hanafy and El-Sayed, 2013) [42, 23]. From the first moment of *T. absoluta* detection, the primary control strategy in Egypt is chemical control (Taha *et al.*, 2017 and Hassan, 2015) [42, 3]. This chemical practice were mainly owing to the side effects on the beneficial fauna in the crops. Moreover, *T. absoluta* is rapid to develop resistance to various chemical pesticides (Gontijo *et al*., 2013) [22]. Therefore, biological control was one of the most suitable and sustainable tools for controlling of this devastative pest (Zappalà *et al*., 2013) [50]. Moreover, the biological control is effective tool in various agricultural systems including sustainable, organic and conventional agriculture (Saleh *et al*., 2017) [40]. For example, many predator and parasitoid species revealed different adaptation levels to this lepidopteran pest (Mollá *et al*., 2014) [33]. Currently, efforts are being done to better utilize the biological control tactics provided tomato cultivation, such as releasing of several natural enemy species (El-Arnaouty *et al*., 2014) [13]. Among natural enemies of the *T. absoluta*, egg parasitoids as like the *Trichogramma* genus (Hymenoptera: Trichogrammatidae) have been stated as suitable bio-control agents of *T. absoluta* infestations in protected tomato crops

(El-Arnaouty *et al*., 2014) [13]. Both inundative and periodic releases of trichogrammatid species have been utilized in tomato against this pest (Pratissoli *et al*., 2005) [37]. Particularly, Egg parasitoids, *Trichogramma* spp. are esteemed a valuable agent for *T. absoluta* management in various crops. Due to their ability to be mass-reared in a reasonably simple and cost-effective manner as well as the fact that they killed this pest before it truly harms and impacts the crop (Pizzol *et al*., 2012) [36]. Additionally, *T. absoluta* appearance was spurred extensive insecticide use by local tomato cultivations, probably performed multitude of side effects (Mahmoud *et al*., 2016) [29]. Nowadays in Egypt, the tomato borer, *T. absoluta* is managed and controlled via integrated pest management strategies (IPM), in which, biological control is played a predominant element in IPM. Natural Enemies especially egg parasitoid have been large scale used to reduce the T. *absoluta* infestation (Cabello *et al*., 2012) [9]. Many *Trichogramma* species including *Trichogramma euproctidis* (Girault, 1911) were more general parasitoids on *T. absoluta* eggs, by which it's likely to parasitize of different species (Knutson, 1998) [28]. In Egypt, El-Arnaouty *et al*. (2014) [13] stated the efficiency of *Trichogramma* species, *Tr. achaeae* and *Tr. euproctidis* for reducing *T. absoluta*. Both *Trichogramma* species were showed a significantly efficient with highly rate of releasing to suppress of *T. absoluta* mines. Moreover, Adly and Nouh (2019) [1] implement the combined the releasing the egg parasitoid, *Tr. euproctidis* with the nematode application, *Heterorhabditis bacteriophora* strain HP88 for *T. absoluta* controlling in tomato plants under greenhouses. This pest monitoring was conducted by sexual baited pheromone or colour traps (Ferrara *et al*., 2001) [18]. Then, insecticide treatments were applied with the selected agents (Taha *et al*., 2017) [42]. Conventional and an integrated management on tomato cultivations to assure the attracted of *T. absoluta* moths to baited sexual pheromone traps (Yadav *et al*., 2022 and Taha *et al*., 2014) [12, 42]. The used of pheromone traps as tactic element combined with foliar spray of insecticides including thiamethoxam, chorantraniliprole, chlorfenapyr and spinosad as an integrated method for *T. absoluta* was conducted by Taha *et al*. (2017) [42]. However, Robredo and cardenoso (2008) [38] conducted that *T. absoluta* infestations can be sued by pheromone mass trapping before planting. This pest caught by a pheromone trap was highly related with entire larvae in tomato leaves in tomato crops were studied by Benvenga *et al.* (2007) [7]. On the other direction, The Ferolite-TUA trap, is a combination of sexual pheromone and a specific frequency of light source, was highly attracted of *T. absoluta* female and male moths. The major components of *T. absoluta* sex pheromone was identified as (E, Z, Z) - 3, 8, 11- tetradecatrien-1-yl acetate/ or (E3 Z8 Z11-14 Ac) (Attygalle *et al*., 1995) [6]. In addition, a miner component (<10 of volatile constituent) was registered as 3E, 8Z tetradecadien-1-yl acetate (Fihlo *et al*., 2000). The design used in sexual pheromone trap was played an important role in T. absoluta catches, as those conducted by Zalom *et al*. (2008) [49], in which, similar catches was found when used pherocon 1-C and delta traps in monitoring for the tomato pinworm, *Keiferia lycopersicella*. In addition, the sexual pheromone load and lifetime of the traps emissions was determined the efficacy of sexual pheromone traps (Alfaro *et al*., 2009) [2]. They reported that the initial pheromone loaded 14 weeks. Moreover, the concentration of synthetic major component (3E, 8Z, 11Z-tetradecatrienyl acetat) was also stated the the efficacy of the *T. absoluta* catches by trap designs (Ferrara *et al*., 2001) [18]. Salas (2007) [39] determined the capture of *T. absoluta* per baited sex pheromone traps with 95% of 3E, 8Z, 11Z Tetradecatrienyl acetate +5% of 3E,8Z-Tetradecadienyl acetate, dispensed in rubber septa in tomato crops using both water and delta sticky traps. The synthetic sex pheromone traps has been e used for monitoring and matting disruption for *T. absoluta* on tomato cultivations (Taha *et al*., 2013) [42]. Efficiency of aggregated traps or matting disruption might be affected by numerous factors as the composition and concentration of pheromone, pheromone dispenser, duration of lures, trap design, and climate, etc. (Taha, *et al*., 2014 and Hassan, 2015) [42, 3]. Since the tomato borer is a serious lepidopteran pest in tomato crops, the previously mentioned elements might be considered in designing a good pheromone trap to catch of moths. Alternative control strategies such as natural products that derived from plants concerning plant oils are suitable for use in integrated pest management (IPM) programs. Due to the rapidly degradation and less side effect on natural enemies, therefore, it was considered eco-friendly bio-pesticides than synthetic pesticides (Srivastava *et al*., 2020) [27]. In addition, Archana *et al*. (2022) [4] advised that biological agents were widely utilized in integrated pest management programs. Plant oils had been useful for controlling numerous agricultural pests during the growing season (Broza *et al*., 1988) [8]. Safety biological applications including orange oil, pepper and garlic extracts and olive soap were evaluate in management of *T. absoluta* on Lebanese tomatoes under organic field conditions (Frem *et al*., 2023) [20]. According to these above mentioned studies, this study achieved to assessing the efficiency of *Tr. euproctidis* releasing and the performance or efficiency of four commercial sex pheromone capsules for controlling *T. absoluta* infestation under greenhouse conditions, after that, it used for management this pest in tomato field in Egypt.

Material and methods

Trichogramma euproctidis (girault, 1911) releases

This study was conducted on tomato crop under greenhouse in Hana-Habib village, El-Fayoum governorate, Egypt, from July-August during 2022. The experimental area contained four greenhouses, each greenhouse (9 width x 60 length) divided into three plots. All releases were repeated three times in a randomized complete block design. The releasing technique and treatment of *Tr. euproctidis* was obtained from Plant Protection Institute, ARC, Egypt, it was reared as a described method of El-Wakeil (2007) [15]. Three release rates of *Tr. euproctidis* were conducted. Each of releasing was applied in separately greenhouse. The 1st, 2nd and 3rd release rates was applied with *Tr. euproctidis* cards contained ~ about 1500 parasitized eggs/card, respectively. All *Trichogramma* cards were released 5 m distance. However, there were fourth greenhouse left without any application as control. After 7 days of releases throughout July-August during 2022, samples of 10 leaves/ replicate/ each *Tr. euproctidis* release were randomly collected in paper bags and then transferred to laboratory for inspection using binocular stereomicroscope. The mean numbers of *T. absoluta* eggs and larvae were recorded after *Trichogramma* treatments.

Sex pheromone evaluations

This evaluation was implemented on tomato crop under greenhouse in the same location of *Trichogramma* treatments through September-October during 2022. The experimental area contained four greenhouses (each greenhouse: 9 width x 60 length) to determine the efficacy of five sex pheromone formulations on the catches of *T. absoluta* male. The fifth greenhouse left without any treatment as control. Four commercially available sex pheromone lures of *T. absoluta* moths were evaluated (Table 1). The field evaluation of were performed by placing standard red delta traps baited with selected lures under greenhouse conditions for about 8 weeks. Traps were placed and installed by strongly metal wire and were contained individual lures. The *T. absoluta* male moths captured by trap were counted and recorded every 3-4 days from 5th September to 21st October 2022. In addition, the red sticky delta trap without sex pheromone was placed in the fifth greenhouse as control. After each count of attracted moths of the tested four sex pheromone lures, the sticky sheet of the delta trap was replaced by new one.

Table 1: The selective of sex pheromone lures

No.	Trade name	Active ingredient	Concentration/ dispenser	Rate of application
A	TUTA-100N	(E,Z,Z) -3,8,11-Tetradecatrienyl acetate	3 mg/ dispenser	2 dispensers/ Feddan
B	Nova Tuta-Plus	(E,Z,Z)-3, 8,11-Tetradecatrienyl acetate (95%) + 3E,8Z Tetradecatrienyl acetate (5%)	0.5 mg/ dispenser	2 dispensers/ Feddan
C	Local pheromone lure	3E,8Z,11Z-Tetradecatrienyl acetate	0.1 mg/ dispenser	2 dispensers/ Feddan
D	Tutacap-long life	(E,Z,Z)- 3,8,11- Tetradecatrienyl acetate	1.5 mg/ dispenser	2 dispensers/ Feddan

Field assessment

Field experiment was conducted during summer season 2023 to compare an integrated pest management (IPM) tactics against *T. absoluta* with untreated field (control) from 3 March to 19 May 2023 at Hana-Habib village, El-Fayoum governorate, Egypt. The tomato seedlings, K186 variety were cultivated on 15 February 2023 in 1/2 feddan. The tomato plants was received standard practices. IPM tactics included the applications of some bio-products and sexual pheromone trapping by using TUTA-100N capsule in red plastic basin water traps (about 10 traps/ feddan) (Table 2), these traps were put at tomato-planting until harvest. Traps were set up about 50 cm above the canopy and 50 m apart. The catch moths were weekly removed from traps and replenish water and detergent in traps. The newly pheromone capsule were added to the old capsule every 6 weeks. The control field kept a distance from IPM field by about 5 feddans apart in the same location. Control field cultivated by the same tomato variety was non-treatments and two pheromone traps using water-basin traps. *T. absoluta* infestation was weekly established by counting of the numbers of eggs, larvae and mines caused by larvae per leaf in a random sample of 30 leaves from each replicate. All treatments had three replicates. The catch males weekly detected and counted in traps in all treatments.

Statistical analysis

The obtained data were statistical analyzed by using SAS computer program (SAS, 2004) [41]. The means were compared by Anova analysis, T-Test, F-test and calculated least significant difference (LSD) by using SAS program.

Table 2: list of applications used in IPM tactics against *Tuta absoluta* during summer season 2023

Treat. date	Trade name	Conc. & Form.	Active ingredient	Rate of application
1st March	Neemix 4.5%EC	4.5%EC	Azadirachtin	500 cm/Feddan soil injection
10th March	Prev-AM 6% SL + Captivaprim 86% SC	6%SL+86%SC	Orange oil (d-Limonene)+ a mixture of Capsicum oleoresin extract 7.6%+garlic oil 23.4%+55% canola oil	400 cm/100 L +100 cm/100 L
15th March	Palmetto gold 25% EC	25%EC	Citronella oil 5%+ Jasmine oil 5%+ Mineral oil 15%	100 cm/100 L
20th March	Jescanim 1% EC	1%EC	Azadrichtin	125 cm / 100 L
25th March	Releasing of egg parasitoid *Tr. euproctidis*	——	*Trichogramma euproctidis*	60 cards/ Feddan
10th April	Xentari 54%WG + Releasing of *Tr. euproctidis*	54%WG	Bacillus thuringiensis subsp. aizawai, strain ABTS-1857 + *Tr. euproctidis*	500 g/Feddan + 60 cards/Feddan
20th April 1st May	Releasing of *Tr. euproctidis*	——	*Trichogramma euproctidis*	60 cards/ Feddan

Treat. = treatment **EC**= Emulsifiable Concentrate **SC**= Suspension Concentrate **SL**= Soluble concentrate
WG= Water-dispersible Granules **Conc.**= concentration Form= Formulation **L**= litre

Results and discussion

1. **Impact of the rate of *Trichogramma euproctidis* releases on *tuta absoluta* eggs and larvae**

In field evaluations, rates of 35, 50 and 60 cards per feddan of the parasitoid, *T. euproctidis* was conducted for reducing the *T. absoluta* eggs and larvae up to 20 days after releases (DAR) on tomato crop. The higher release rate had fewer *T. absoluta* eggs and larvae on tomato leaves. Date in Table (3) showed that a significant value between the 1st releasing and the two other rates of *Tr. euproctidis*, the highly mean reduction % of *T. absoluta* eggs/ leaf was 93.93 and 92.64% in 50 and 60 cards/feddan, respectively. While, low reduction % was 80.46 in 35 cards of *Tr. euproctidis* /feddan after 7 DAR. However, in case of 10 DAR, the low reduction in *T. absoluta* eggs on tomato plants was 44.93 and 52.24 in in 35 and 50 cards of *Tr. euproctidis* /feddan, but the highly reduction percentage was found with 60 cards of *Tr. euproctidis* release/feddan. After both 14 and 20 DAR of *Tr. euproctidis*, the reduction in *T. absoluta* eggs/ leaf was statistically categorized two three types: 'a' type is a highly effective rate in reducing of *T. absoluta* eggs in 60 cards of *Tr. euproctidis*/ feddan, 'ab' is the intermediate type with the rate of 50 cards, and 'b' type is the low effective rate on the reducing of *T. absoluta* eggs per tomato leaf. In Table (3), the overall reduction % of *T. absoluta* eggs / tomato leaf was a high value of 78.55% in 60 cards of *Tr. euproctidis* release/feddan. On the other hand, the low reduction % of 57.42 and 64.30% in *T. absoluta* eggs / tomato leaf with 35 and 50 cards of *Tr. euproctidis* /feddan (Table 3). In case of tomato borer larvae, up to 10 days after releasing, the using of 35 cards per feddan of the parasitoid, *Tr. euproctidis* was recorded a significant higher value than other two rates of *T. euproctidis*. The reduction percentage of *T. absoluta* larvae/ leaf was 91.38 and 72.94% after 7 and 10 DAR, respectively (Table 4). After that, the higher releasing rate of the parasitoid, *Tr. euproctidis* was stated a highly reducing in T. absoluta larvae/ leaf with 60 cards of *Tr. euproctidis*/ feddan being 75.68 and 86.28 % after 14 and 20 DAR, respectively. In Table (4), the overall reduction % of T. absoluta larvae / tomato leaf was a high value of 74.53% in 60 cards of *Tr. euproctidis* release/feddan. On the other hand, the low reduction % of 61.00 and 59.02% in *T. absoluta* larvae / tomato leaf with 35 and 50 cards of *Tr. euproctidis* /feddan (Table 4). Generally, the releasing of 60 cards of *Tr. euproctidis* /feddan differed significantly comparing to the other rates of *Trichogramma* in dead larvae numbers of *T. absoluta*. So that, the releasing of 60 cards of *Tr. euproctidis* /feddan is the best rate that had been recorded by increasing the reduction of *T. absoluta* eggs and larvae than other treatments (Table 3, 4).

Table (3): Releasing of *Tr. euproctidis* against tomato borer *T. absoluta* eggs during 2022

Treatments		Mean numbers/ leaf before releasing	Mean numbers and reduction percentage of tomato borer *Tuta absoluta* eggs/ leaf after treatment								
			7 DAR	R%	10 DAR	R%	14 DAR	R%	20 DAR	R%	Overall R%
35 cards /feddan	Control	2.17	7.33	80.46 b	6.17	52.24 b	9	44.37 b	10.67	52.60 b	57,42 b
	TRT	2.83	1.67		3.83		6.67		6.0		
50 cards /feddan	Control	2.5	7.83	92.64 a	4.0	44.93 b	7.17	57.76ab	8.83	61.85ab	64.30 b
	TRT	3.97	0.83		2.83		4.83		5.5		
60 cards /feddan	Control	4.83	5.5	93.93 a	3.83	80.06 a	4.67	65.20 a	6.33	75.00 a	78.55 a
	TRT	4.47	0.33		0.67		1.67		1.5		
F value			————	5.50	————	23.28	————	5.44	————	6.11	5.47
LSD				10.971		13.293		15.665		15.756	13.261
Pr > lFl				0.044		0.002		0.045		0.036	0.009

DAR= days after treatments**, TRT**= Treatment, **R%**= Reduction percentage

Table (4): Releasing of *Tr. euproctidis* against tomato borer *T. absoluta* larvae during 2022

Treatments		Mean numbers/ leaf before releasing	Mean numbers and reduction percentage of tomato borer *Tuta absoluta* larvae/ leaf after treatment								
			7 DAR	R%	10 DAR	R%	14 DAR	R%	20 DAR	R%	Overall R%
35 cards /feddan	Control	6.17	6.17	91.38 a	3.5	72.94 a	4.67	38.61 b	6.33	41.07 c	61.00 b
	TRT	4.6	0.5		0.83		2.0		2.67		
50 cards /feddan	Control	3.17	6.83	68.45 b	5.67	41.77 b	14.67	63.86 a	16.33	62.00 b	59.02 ab
	TRT	4.0	1.5		3.67		5.67		7.17		
60 cards /feddan	Control	1.83	6.83	85.74 a	5.17	50.44 b	13.83	75.68 a	15.5	86.28 a	74.53 a
	TRT	5.5	3.33		5.17		7.33		6.67		
F value			————	8.09	————	20.98	————	22.93	————	33.28	2.62
LSD				14.536		12.155		13.684		13.571	15.014
Pr > lFl				0.0198		0.002		0.0015		0.0006	0.088

DAR= days after treatments**, TRT**= Treatment, **R%**= Reduction percentage

In the present study, the egg parasitoid, *Tr. euproctidis* (Hymenoptera: *Trichogramma*tidae) have been stated as a suitable bio-control agents against *T. absoluta* infestations in protected tomato crops The obtained data showed that the releasing of 60 cards of *T. euproctidis* /feddan differed significantly comparing to the other rates of *Trichogramma* in reduced larvae numbers of *T. absoluta*. So that, the releasing of 60 cards of *Tr. euproctidis* /feddan is the best rate that had been recorded by increasing the reduction of *T. absoluta* eggs and larvae than other treatments. Similarly, Adly and Nouh (2019) [1] reported that the releasing of *Tr.euproctidis* by the rate of 50 parasitoids/m^2 resulted to gradually reduce of *T. absoluta* density until the end of the season in tomato greenhouses. In addition, El-Arnaouty *et al*. (2014) [13] observed that *Tr. euproctidis* might be more adapted than *Tr. achaeae* in hot and drier conditions against *T. absoluta*. These environmental conditions is an important crucial step when evaluating the fitness of *Trichogramma* spp. (Yuan *et al*. 2012) [47]. Under cropping conditions, Chailleux *et al*. (2012) [10] stated that the more efficient *Trichogramma* species against *T. absoluta* was still *Tr. euproctidis* than *Tr. achaeae* at all three tested doses. This *Tr. euproctidis* may be more adapted to Egyptian conditions than other *Trichogramma* species (El-Arnaouty *et al*. (2014) [13]. Generalist predators as *Nesidiocoris tenuis* (Reuter) (Heteroptera: Miridae) and *Chrysoperla carnea* Stephens (Neuroptera: Chrysopidae) have been recorded and used against this pest in Egypt (El-Arnaouty and Kortam 2012) [13]. These obtained results highlight how crucial it is to include predator presence in greenhouse tomato crops when employing oophagous parasitoids for *T. absoluta* inundate biological control. Furthermore, we would support the use of *Tr. euproctidis*, for a safe and successful inclusion in IPM programs against tomato borer, *T. absoluta* in Egypt.

2. Efficacy of sex pheromone lures for catching of *tuta absoluta* male moths

The catching of certain commercial pheromone formulations and longevity of lures were evaluated as firstly step to determine the effective of sexual pheromone traps for developing IPM for tomato borer *T. absoluta* in tomato crop. Total number of caught *T. absoluta* male moths recorded during the period of September-October during 2022 is illustrated in Figure (1). The attractiveness of the tested sex pheromone formulations was recoded a highly attractive to male moths exceed than 4 weeks in tomato plants (Figure 2). After that, the catch capacity of all lures declined steady until the experimental end. Red basin water traps baited with sexual pheromone type,'Tuta 100N' significantly higher caught males (254.31 moths/ trap) than the other tested pheromone types. While, the lowest caught males was found with using of the local type for sexual pheromone (121.38 moths/ trap) (Figure 1). No significant difference was found between the sexual pheromone types, Nova Tuta-Plus, Tutacap-long life and Local pheromone lure which recorded the average number of caught males was 153.64, 133.40 and 121.38 moths/ trap, respectively (Figure 1). Finally, among of them, Tuta 100N baited with3 mg/ dispenser of (E,Z,Z) -3,8,11-Tetradecatrienyl acetate caught relatively high numbers of males than other investigated sexual pheromone traps. Data showed in Figure (2) the degradation and performance of sexual pheromone lures throughout the experiment period. The red-water traps baited with Tuta 100N synthetic pheromone remained attractive to male *T. absoluta* moths up to 45 days. However, the other three tested sexual pheromone types was remained attractive to T. absoluta moths up to 30 days, so that, there must renew with fresh capsule after one month. The maximum caught of *T. absoluta* males was observed at 16 September 2022 being 637.0, 417.0, 338.3 and 337.0 moths/ trap in Tuta 100N, Tutacap-long life, Nova Tuta-Plus, Local pheromone commercial lures, respectively. Two peaks of adult attractiveness was found with Tuta 100N and Nova Tuta-Plus commercial lures during the experiment, while, one peak was observed with Tutacap-long life and Local pheromone commercial lures. In view of data in figure 2, it should be add or renew of fresh dispenser for all tested commercial sexual pheromone lures after 30 days except the sex pheromone type, Tuta 100N was renewed after 45 days (Figure 2).

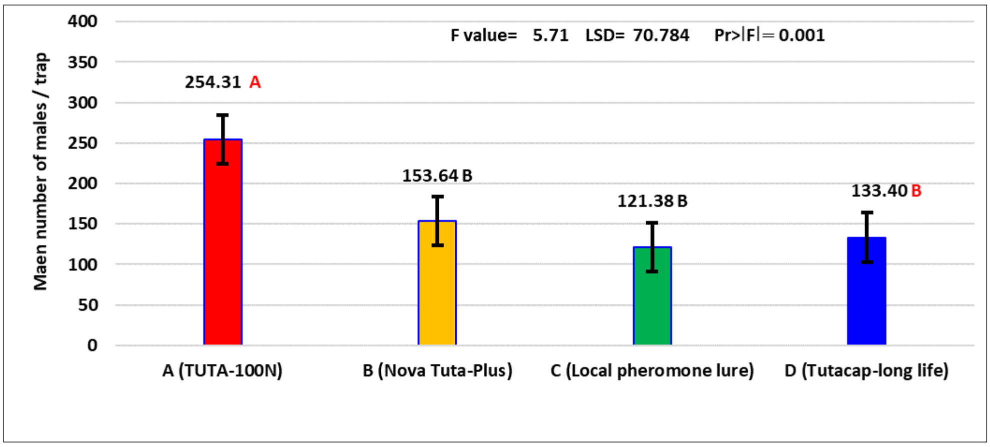

Fig 1: efficacy of sexual pheromone formulations for attractive *T. absoluta* male moths

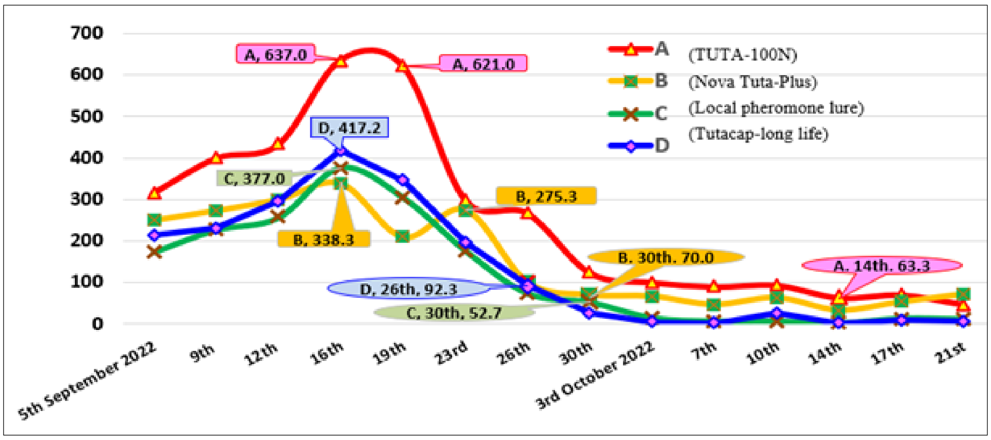

Fig 2: efficacy of sex pheromone lures longevity for attractive *T. absoluta* male moths

In the present work, the obtained data indicated that the utilized of sexual-pheromone basin water trap was important tactic for monitoring and controlling tomato borer on tomato cultivations. Additionally, The data showed that Tuta 100N baited with3 mg/ dispenser of (E,Z,Z) -3,8,11-Tetradecatrienyl acetate caught relatively high numbers of males than other investigated sexual pheromone traps. Similarly, it was frequent according to Ferrara *et al* [18]. (2001) reported that the synthetic structure, (3E,8Z, 11Z)-3,8,11- tetradecatrienyl acetate was highly attractive to male moths. In which, the best trap baited with 100µg of lure pheromone caught about 1200 males/trap/ night. Also as well, Taha *et al*. (2014) [42]and Hassan (2015) [3] stated that the highly caught males of *T. absoluta* was was observed with as commercial product Tuta 100N followed by Tutacap longlife, Tuta lure, Tryferron and Tutasan being 341.2, 294.6, 292.33, 269.47, and 186.47 males/trap tomato cultivations, respectively. Otherwise, Chermiti and Abbes (2012) [11] reported that the three types of sexual-capsule concentrated by 0.5 and 0.8 mg/ capsule. They stated that the dispenser type contained 0.8 mg can attract more males than the other capsule contained 0.5 mg. In addition, in the present study, the attractiveness longevity for the tested commercial sexual pheromone lures was powerful up to 30 days. It was in line with those findings by Taha *et al*. (2014) [42] and Hassan (2015) [3]. They recorded that a significant degradation of lure performance was depend on the high density of sex-pheromone dispenser. The attractive capacity percentage was powerful up to 45 days for fresh lures in case of Tuta 100N, Tuta lure and Tutacap longlife commercial lures. Contrariwise, the lifetime emission of sexual-pheromone trap was highly effective up to 9th week for *T. absoluta* moths trapped per day (Alfaro *et al*., 2009) [2]. Otherwise, Núñez *et al*. (2009) [35] noticed that the trap captures was reached to 96% for 78 days after the installation of lure capsule. The longevity of sexual-pheromone lures may be affecting by numerous factors as kind and composition of a rubber of dispenser, moreover, the concentration and formulation of active ingredient, the percent of emission, intensity and speed of the wind and exposed temperature were play an important factors affected the sexual pheromone trap. As well as, McNeil (1991) [30] reported that temperature is mainly factor affect the emission and reception of pheromones. Finally, the best pheromone lure types is Tuta 100N followed by Tutacap longlife commercial products. Accordingly, these obtained data suggested that a monitoring and controlling program for the tomato borer, *T. absoluta* should consist of sexual-pheromone lure type 'Tuta 100N' with 3mg/ dispenser placed in red water trap and lures should be replaced after 6 weeks.

3. The application of IPM tactics against *T. absoluta* on tomato open field during summer season 2023

The deposited eggs of *T. absoluta* on tomato plants were ranged from 0.5 to 3.2 and 0.8 to 6.2 eggs/ leaf in treated and control fields, respectively (Table 5). The population fluctuation of Tomato borer eggs and larvae was recorded 2 peaks on all treated tomato plants, while it was observed 3 peaks on all control field during summer season 2023. The highest mean number of Tuta absoluta was 3.2 eggs/ leaf at 28th April in treated field while it was 6.2 eggs/ leaf at 17th march in control field, respectively. However, the high values of larvae was noticed at 24th march (2.6 larvae/leaf) in the treated field and at 28th April (5.2 larvae/ leaf) in control field (Table 5). In view to data in Table (5), the overall mean numbers of tomato borer was higher in control field than treated field. A highly significant differences was statistically detected between the treated (IPM program) and control tomato fields (probability at 5 level equal 0.002 and 0.0001 with eggs and larvae, respectively). In IPM program (treated field), the resulted a decreasing tomato borer, *T. absoluta* mines according to reduce the mean numbers of larvae/ leaf through summer season, 2023 (Table 5). Abundance of caused by *T. absoluta* larvae remained low infestation in treated program than control field throughout summer season, 2023. Three peaks were noticed in control and treated fields. According to sexual pheromone based control strategies in two programs, the capture male of Tuta absoluta using sex pheromone trap (TUTA-100N capsule) recorded lower caught number of 71.38 males/trap/week during 2023 season in treated plot (IPM field) than in control field with three peaks (111.27 males/trap/week). There were significant differences between them. The maximum capture of male moths were 236.7 and 154.8 males/ trap/ week in the control and treated fields at 24th march 2023, respectively. The sexual pheromone based water trap was noticed highly significant catches of *T. absoluta* male moths in the treated field (IPM tactics) than control field (untreated plot) (Probability > |t| equal 0.0071, Table 5). Results recorded that *T. absoluta* male population was ranged from 10.0 –154.8 and 19.4 – 236.7 males/trap/week in control and IPM fields, respectively (Table 5). Finally, the overall larval activity of *T. absoluta* that caused mines in tomato leaves during summer season, 2023 was higher in control field than in IPM field program.

Table 5: The application of some IPM tactics against *T. absoluta* on tomato open field during summer season 2023

Inspection dates	Mean numbers of Tomato borer *T. absoluta* on tomato plants							
	Eggs/ leaf		Larvae/ leaf		Mines/ leaf		Attracted moths/trap	
	Treated	Control	Treated	Control	Treated	Control	Treated	Control
3rd March 2023	0.8	0.9	0.0	0.4	0.0	0.4	10.0	19.4
10th	1.2	2.2	1.0	1.2	0.0	2.1	43.3	52.3
17th	2.4	6.2	1.8	2.7	1.0	2.1	139.3	228.6
24th	1.7	2.1	2.6	4.6	4.4	8.1	154.8	236.7
31st	1.6	1.6	2.5	2.6	0.9	7.2	125.2	194.1
7th April 2023	0.9	1.3	1.0	2.3	1.8	3.9	43.7	67.1
14th	0.5	0.8	0.8	1.8	0.6	1.9	17.8	68.3
21st	1.7	1.9	0.6	3.3	0.6	6.0	76.8	102.3
28th	3.2	5.2	1.0	5.2	2.5	8.0	92.6	103.4
5th May	2.1	2.2	0.3	2.5	1.5	4.9	45.7	79.6
12th	0.8	3.8	0.3	2.8	1.2	2.4	33.4	76.3
19th	1.8	2.9	0.2	1.9	1.0	4.2	74.0	107.0
Overall Mean	**1.54**	**2.60**	**1.01**	**2.60**	**1.30**	**4.28**	**71.38**	**111.27**
t value	-3.22		-5.79		-5.74		-2.78	
Pr>|t|	0.002**		<0.0001**		<0.0001**		0.0071**	

** High significant

Because it reproduces quickly on various host plants, the tomato borer, *T. absoluta* is a difficult lepidopteran pest to control. So that, IPM program techniques, including foliar spraying of sequence biocontrol agents including azadirachtin, mixture of d-Limonene+ *Capsicum oleoresin* extract +garlic oil + canola oil, a mixture of citronella oil + jasmine oil + mineral oil, *Bacillus thuringiensis* subspecies *aizawai* and four releases of parasitoid *Tr. euproctidis* and using sexual pheromone traps are effective in controlling *T. absoluta* (as shown in Table 2). Similarly, during the initial planted until tomato harvest, Taha *et al*. (2017) [42] used a combination of pheromone lures and various insecticides to manage the tomato borer. Moreover, Adly and Nouh (2019) [1] detailed that the combined utilized of *Tr. euproctidis* (50 parasitoids/m^2), *Heterorhabditis bacteriophora* strain HP8 and synthetic insecticides resulted to significantly reduce the population density of the *T. absoluta* gradually until the end of the season in tomato greenhouses. The obtained results in this research show a relevant efficiency of *Tr. euproctidis* behind bio-pesticides in keeping the damage levels of *T. absoluta* under an acceptable threshold, when compared to the untreated control plants. Otherwise, Hassan (2015) [3] found that the mean number of *T. absoluta* eggs, larvae, mines, and male adults in fields with used pheromone-baited traps in conjunction with insecticide applications (IPM program) was significantly lower (0.11 egg, 0.06 larva, 0.08 mine/leaflet and 216.33 adults/trap) than in fields treated with insecticides (farmer field) (1.04 eggs, 1.20 larvae, 1.91 mines/leaflet and 224.40 adults/trap). In the present study, the utilized of the selected bio-products and sexual pheromone trapping by using TUTA-100N capsule in red plastic basin water traps (about 10 traps/ feddan) altogether gave a good protection of tomato cultivations than other fields without any treatments. Similarly, Taha *et al*. (2017) [42] recommended the using of red mass traps by 8 traps/ feddan combined with used with selected insecticides for controlling *T. absoluta*. They found that the farmer field (check field) had greater tomato fruit damages (39.16% fruit damages) than the field treated with pheromone baited water traps (37.44% fruit damages). The present results agree with the previous studies which revealed that *Tr. euproctidis* when released at high rate can control *T. absoluta* with the selected tactics of bio-control products. As well as in Tunisia, Asma *et al*. (2019) [5] discovered that *Tr. cacoeciae* is a promising an ecofriendly management tactic against *T. absoluta* in the tomato-producing area. In the obtained data, the releasing rate of 60 cards of *Tr. euproctidis* / feddan used with biopesticides: azadirachtin, orange oil (d-Limonene) + a mixture of *Capsicum oleoresin* extract 7.6%+garlic oil 23.4%+55% canola oil, a mixture of citronella oil 5%+ jasmine oil 5%+ mineral oil 15%, *Bacillus thuringiensis* subsp. *aizawai*, strain ABTS-1857 was the most effective rate that caused significantly decreasing of this pest densities. There are in the line of those findings by Mustapha *et al*. [34] (2018), they applied the individually and combination effect of azadirachtin, *Bacillus thuringiensis*, *Beauveria bassiana* and *Steinernema feltiae* under both laboratory and greenhouse conditions that can contribute to suppress *T. absoluta* infestations. The potential for including the bio-pesticides in an overall sustainable IPM for tomato borer *T. absoluta* was discussed. Frem *et al*. (2023) [20] evaluated the effect of biological treatments (*Bacillus thuringiensis*, orange essential oil, pepper & garlic extract, pepper extract, garlic extract, and olive soap) in controlling *T. absoluta* on Lebanese tomatoes in organic open field conditions. In this research, plant extracts such as azadirachtin, orange oil (d-limonene), *Capsicum oleoresin* extract, garlic oil, canola oil, citronella oil and jasmine oil act as insecticide for *T. absoluta* on tomato cultivations. Moreover, these plant extracts may be caused the inhibition of the oxidation enzymes inside the insect larva, additionally, it may be effected on the central digestive tract of the insect on toxic compounds, and the digestive enzymes that leading to the death of the insect (Fan *et al*., 2011) [16]. Also, this toxicity of plant extracts may be due to flavonoid compounds in the plant extracts, which inhibited their insect growth and development (Mesbah *et al*., 2007) [31]. According to studies, the mortality rate of *T. absoluta* larvae increased with the increasing of essential oils concentrations of *Citrus aurantium* and *Citrus limon* contained d-limonone compound, these could be useful for the investigation of new biopesticidal compounds (Frem *et al*., 2023) [20]. In this study, garlic extract used to reduce *T. absoluta* infestations as shown by with Hussein *et al*. (2015) [26], they discovered a significant reducing in *T. absoluta* density on tomato and worms, beetles, and thrips on cowpea crops after treated by garlic extract. In accordance to these previous study, a thorough research program towards developing certain subsequently tactics in IPM program to suppress *T. absoluta* infestations including a foliar mixture spray of azadirachtin, orange oil (d-limonene)+ a mixture of *Capsicum oleoresin* extract 7.6%+garlic oil 23.4%+55% canola oil, a mixture of citronella oil 5%+ jasmine oil 5%+ mineral oil 15%, *Bacillus thuringiensis* subspecies *aizawai* and sexual pheromone trap (at 10 lure traps/ feddan) with combined releasing of egg parasitoid *Tr. euproctidis* on tomato plant. Such an approach would not only allow for reducing the pest, but also result in a better understanding IPM for the devastated tomato borer, *T. absoluta* in a given region.

Conclusion

Accordingly, this work was conducted by using of biocontrol agents helps in reducing *T. absoluta* infestation, thus it was essential in our study to explore the efficiency of a combination of egg-parasitoid and using of sexual pheromone traps altogether to put the most suitable elements in tomato borer management program.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no conflict of interest.

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