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EFFICIENCY OF DIFFERENT TRAP TYPES FOR ATTRACTING TOMATO LEAF MOTH *Tuta absoluta* UNDER FIELD CONDITIONS

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ABSTRACT

Field studies were conducted in the Sharya-Duhok / Kurdistan Region of Iraq to evaluate the influence of different light colors, three installation heights, and three types of traps on the capture of the tomato leaf miner moth. The light colors tested were yellow, white, green, blue and red. The trap installation heights were 70, 100, and 130 cm above ground level. The traps included a delta trap, a water trap and a new combined pheromone-equipped sticky light trap, referred to as the GLT trap. Results indicated that the white light was significantly more attractive to the tomato leaf miner, capturing 32% of the total moths, followed by the yellow, blue, green and red light with percentages (27, 22, 13, 6%), respectively. This significantly differed from traps installed at heights of 70 cm captured 70% of the total number caught, and it differed statistically from the traps installed at a height of 100 and 130 cm, which captured 19 and 11%, respectively, this suggests that moth flight activity is concentrated at the plant canopy level. The GLT trap demonstrated remarkable superiority over other trap types, capturing 52% of the total moths, significantly differing from the delta and water traps, which captured 37% and 11%, respectively. This suggests that exploiting the pest's behaviors, such as using the GLT trap, could be a promising approach to managing the pest in infested fields within a short period, complementing chemical control methods.

INTRODUCTION

The tomato leaf miner, *Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae), is considered one of the most important pests that attack tomatoes in many tomato-producing regions worldwide, including open fields and greenhouses (Desneux *et al.*, 2010). Since its first report in Castellón, eastern Spain, in 2006 (Urbaneja *et al*., 2007), the tomato leaf miner has spread throughout the entire Mediterranean coast and Europe (Potting *et al*., 2009) posing a significant agricultural threat to tomato production in these regions (Desneux et al., 2010). The pest was first documented in Iraq in 2010 (Abdul Razzak et al., 2010), and since then, it has rapidly expanded to all tomato-growing areas, resulting in economic losses for tomato crops in both greenhouses and open fields (Abdul-Rassoul, 2014). The tomato leaf miner is an oligophagous pest that infects various crops and wild plants within the Solanaceae family (Desneux *et al.,* 2011). It can devastate entire fields of crops and tomatoes in plastic houses if not properly managed (Assaf *et al*., 2013). Generally, the larvae feed on the mesophyll layer inside the host leaves and under heavy infestation, they can also penetrate tender stems, buds, flowers, and fruits, leading to visible superficial holes in the fruits (Mirza,2014).

Insecticide applications are the common method used to manage this pest, however many of them are ineffective due to pest insecticide resistance. Karut *et al.,* (2011) pointed out that despite pesticide use, the percentage of fruit infected with this pest in greenhouses exceeded one-third of the yield. Braham and Hajji (2012) reported that the tomato leaf miner developed resistance to pesticides such as Cartap, Abamectin, Cartap, Permethrin, and Methamidophos in Brazil and to Abamectin, Deltamethrin and in Argentina.

Consequently, researchers have sought integrated pest management (IPM) strategies to control this insect, aiming to reduce reliance on chemical pesticides and instead promote biological control. Urbaneja *et al.,* (2009) and Molla *et al.,* (2011) indicated that mirid predators such as *Nesidiocoris tenuis* (Reuter) and *Macrolophus pygmaeus* (Rambur) were effective in preying on tomato leaf miner eggs and larvae in Spain. However, Oztemiz *et al.,* (2012) explained that releasing the predator *N. tenuis* at a density of 2 individuals per square meter in small cage studies in greenhouses in Turkey resulted in economic damage to tomato crops of up to 10%. Additionally, Mirza (2014) found that controlling this pest using the pathogenic fungus *Beauvaria bassiana* is not feasible except under specific conditions that are typically unavailable in open fields. Despite the potential of biological control agents, they are often not readily available to farmers and may increase production costs, particularly in developing countries.

As an alternative control tactic, mass trapping can be used to reduce the population density of the pest by removing a sufficient number of males and disrupting the mating process (El-Sayed *et al.,* 2006). Mass trapping has been employed to decrease the population of tomato leaf miner adults as a therapeutic measure (Chermiti, 2012; Cocco *et al.,* 2012; Matos *et al.,* 2012; Lobos *et al.,* 2013), however, the effectiveness of such pheromone-based control has been diminished by the ability of female *T. absoluta* to reproduce parthenogenetically (Illakwahhi and Srivastava, 2017).

Due to the fact that the adults are nocturnal and attracted to light sources at nightfall, numerous pheromone traps have been developed to capture them by incorporating a light source (de Oliveira *et al.,*2008, Cocco *et al.,* 2012, Salama *et al.,* 2015). For example, Bloem and Spaltenstein (2011) explained that the incorporation of a light source into pheromone traps resulted in the capture of a significant number of males and females per night. Ardeh *et al.* (2021) indicated that light traps can be effectively reduce pest numbers. However, further research is needed on additional factors and characteristics of light traps, such as light color and trap design. Therefore, the aim of this study is to evaluate these properties and factors to develop a trap that maximizes the capture of tomato leaf miner.

MATERIALS AND METHODS

Study Area

This study was conducted in an open field in the Sharia subdistrict (36.792825° N, 42.944573° E), renowned for growing tomatoes in the Dohuk Governorate, Kurdistan Region of Iraq. One dunum, planted with tomato plants of the GS-12 variety and moderately infested with tomato leaf miner, was selected for this study. However, the trap experiment was conducted on an area of three dunums.

Colored Light Sticky Traps Design

The traps were handcrafted using the following materials: plastic containers made of polyethylene terephthalate (volume 10 L), five colored cloths (red, white, blue, green and yellow), transparent nylon roll, adhesive glue that is used for rats and mice trapping, electric wire, led lamps (10 watts) and wooden poles (1.5 meters) to install traps. The materials were assembled by covering the clear plastic containers with cloths, installing LED lamps in the container lids, and mounting each container on a wooden pole.

Trapping Methods for Adult Males Harvesting

Adult *T. absoluta* were monitored using colored light sticky traps designed specifically for early detection and capture of male tomato leaf miners. The traps were randomly distributed in the field, with a distance of 3 meters between each pole and 8 meters between each block, with three replications. The containers were covered with a layer of transparent nylon coated with adhesive. Electric wires were extended to the lamps installed in the container covers. Colored light sticky traps were turned on from dusk to sunrise, encompassing the period of insect activity. This experiment aimed to assess the attraction of moth adults to different colored lights.

Trap Height Experiment

After determining the most effective colored light trap based on the results of the statistical data from the previous experiment, this trap was installed in this part of the study at three heights (70 cm, 100cm, and 130 cm). The traps were distributed randomly with three replications, with a distance of 6 meters between each height and 8 meters between each block. The light sources of the traps were turned on from dusk to sunrise. This part of the study aimed to determine the best installation height for colored light sticky traps.

2.5. Trap Types Experiment

Finally, three types of traps were installed as follows, 1- the best colored light sticky trap (based on the previous experiment) + pheromone Figure (1b), 2- Delta trap + pheromone and 3- water trap + pheromone. Each trap was positioned at the corner of an imaginary triangle within the dunum, placed at a height of 70cm (based on the previous experiment). To prevent interference between pheromones, the distance between each trap was set at 30 meters. The traps were randomly distributed with three replications. The objective of this experiment was to assess the efficacy of each trap in attracting and capturing the insects. Data were collected in all preceding experiments by recording the number of insects captured in each trap after 1, 3, 5, 7, and 9 days, and the differences between the various traps were evaluated statistically.

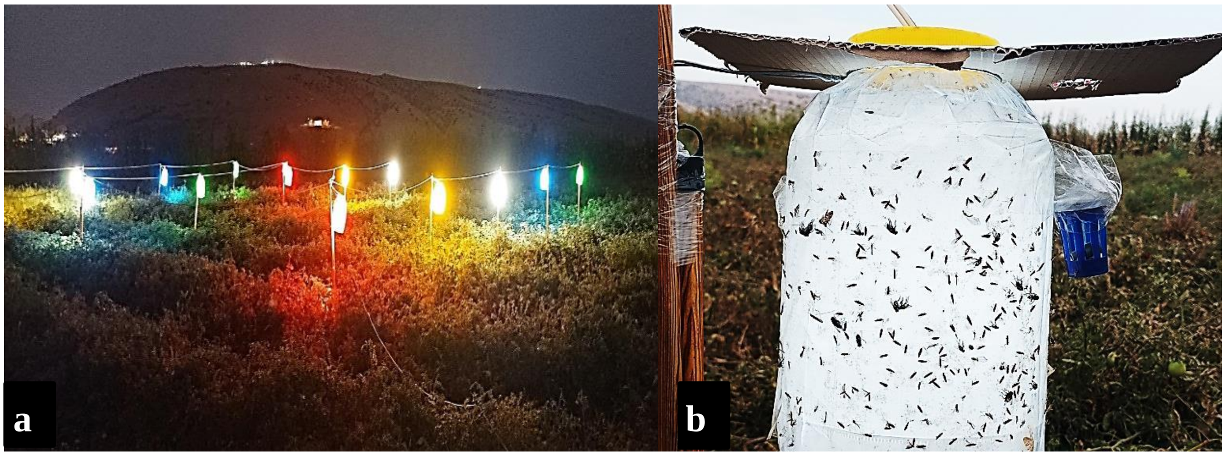

Figure (1): a- Installing colored light traps, b- The GLT trap.

Statistical Analysis

For all experiments, the statistical analysis of the data was performed using the SAS program, employing a Randomized Complete Block Design (RCBD) with three replications. Duncan's multiple range test (DMRT) was utilized to compare the means at a significance level of $P \leq 0.05$.

RESULTS AND DISCUSSION

Colored light sticky traps

The findings of this study supported the first hypothesis that the tomato leaf miner would be differentially attracted to the different color of the light traps. The findings revealed that there were highly significant differences in the capture of moths in terms of the color light traps, the different days, and furthermore, the interaction of the color of the trap and the days Table (1). This indicates that the moths of tomato leaf miners respond differently to different color on various days.

Table (1): Analysis of variance for the studied traits

Source of variance	Probability of significance
	NO. Tomato leaf miner
Colors	<.001
Days	<.001
Colors * Days	<.001

The data in Table (2) showed that all light color traps attracted the adult moths, and the total number of *T. absoluta* moths caught in all traps examined during this experiment period despite the trap color was 2635 moth. Data analysis Table (2) revealed that there were significant differences in the numbers of captured moths, and they differ according to the colors of the traps. The largest number of moth was captured after 9 days followed by 7 days of trapping by the white light color as 281.3 and 262 moth/trap, respectively, while the number of moths captured after 5 days (229.7) significantly did not differ from the number of moths captured by yellow color after 7 and 9 days as 223.7 and 238 moth/trap, respectively. The lowest number of moths was captured after one day of trapping by the red light as 10.7 moth/ trap and significantly did not differ from those captured after 3,5,7,9 days as 31.7, 41.3, 50.7 and 57.3 moth/ trap, respectively. In the daily mean of moths captured in all trap types, the largest number of moths captured was after 9 days as 175.7moths/day which significantly differed from the number of moths captured after 1, 3, 5 and 7 days as 61.8, 111.2, 143.1 and 163.4, respectively. The means comparison showed that the highest attraction average was recorded for the white light sticky traps (211.3 moths /trap), which differed significantly from the other traps. The number of captured adults for the yellow and blue lights was 178.2 and 140.6 moth/ trap, respectively. The lowest capture was recorded with the red light traps as 38.3 moth/ trap.

The results of this study are harmonious with the laboratory results of the (Ardeh *et al.*, 2021) study which showed that the white and yellow traps attracted a greater number of tomato leaf miner and differed significantly from the green, blue, and red light traps. On the other hand, the field results of the (Mangrio *et al.*, 2023) study showed that the green and red light traps captured a significantly lower number of tomato leaf moths compared to the white and yellow light traps.

Table (2): Effect of colors, days and their interactions on the cumulative number of tomato leaf miner moth.

Days	Number of tomato leaf miner moth					
	Red	Green	Blue	Yellow	White	Means of days
1	10.7 n	37.7 mn	71.7 jkl	84.3 hijk	104.7 ghi	61.8 ^{e}
3	31.7 mn	78.3 ijkl	119.0 g	148.0 f	179.0 de	111.2 ^{d}
5	41.3 m	93.7 ghij	153.7 ef	197.0 d	229.7 c	143.1 ^{c}
7	50.7 lm	108.3 gh	172.3 def	223.7 c	262.0 ab	163.4 ^{b}
9	57.3 klm	115.3 g	186.3 d	238.0 bc	281.3 a	175.7 ^{a}
Mean of colors	38.3 ^{e}	86.7 ^{d}	140.6 ^{c}	178.2 ^{b}	211.3 ^{a}	

Means followed by same letter within each case are not differ significantly according to DMRT ≤ 0.05

Figure (2) shows that the tomato leaf miner moth has the ability to distinguish between white, yellow, blue, green, and red lights and the highest percentage of capturing was recorded by the white light as 32%, which was more than the duplicate number captured by green light (13%) and five times in red color (6%).

Trap height experiment

After determining the most attractive light for capturing the tomato leaf miner moth which was a white light color, it was necessary to verify the determination of the best height of the trap. The data in Table (3) showed that the largest number of moths were captured after 7 days followed by five days of trapping at 70 cm. height as 318.3 and 246.7 moth/trap, respectively, while the lowest number of moths were captured after one day of trapping at 130 cm. and 100 cm. height as 9.0 and 22.7 moth/trap, respectively and significantly did not differ from the number of moths captured at 130 cm after 3,5 and 7 days of trapping as 28.3, 39.7 and 50.3 respectively. In the daily mean of moths captured in all trap types, the largest number of moths captured was after seven days as 152.4 moths /day and significantly differed from the number of moths captured after 1 and 3 days as 34.3 and 80.2, respectively.

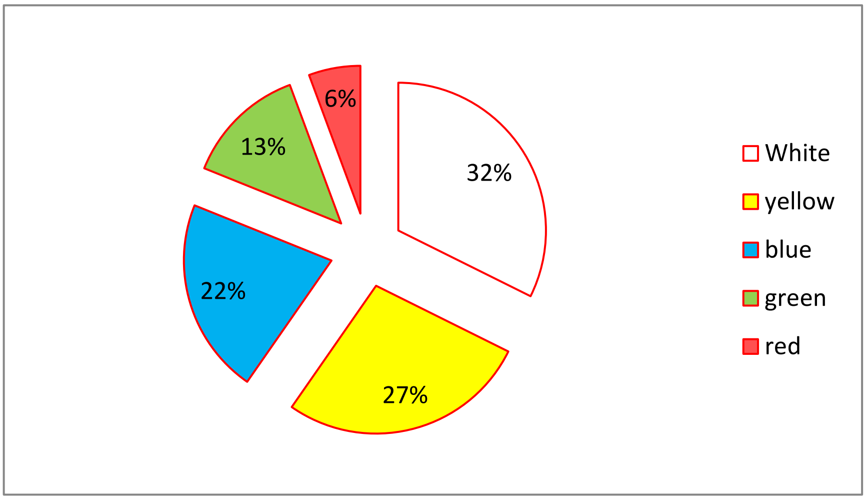

Figure (2): The percentages of the tomato leaf miners captured by the different sticky Light- colored traps in 9 days.

Table (3): Effect of heights, days and their interactions on the cumulative number of tomato leaf miner moth.

Days	Number of tomato leaf miner moth			
	70 cm	100 cm	130 cm	Means of days
1	71.3 cd	22.7 d	9.0 d	34.3 [c]
3	165.7 bc	46.7 d	28.3 d	80.2 [bc]
5	246.7 ab	69.0 cd	39.7 d	118.4 [ab]
7	318.3 a	88.7 cd	50.3 d	152.4 [a]
Mean of heights	200.5 [a]	56.8 [b]	31.8 [b]	

Means followed by same letter within each case are not differ significantly according to DMRT ≤ 0.05

The highest average number of moths was captured in traps with a height of 70 cm reached 200.5 moths and differed significantly from the traps installed at 100 and 130 cm height as 56.8 and 31.8 moths respectively. These results are harmonious with the laboratory findings of the Ardeh *et al.* (2021) study when tested three heights (50, 75 and100) cm. They recommended installing light traps at a height of 75 cm. Ferrara *et al.*, (2001) indicated that the height of the trap and its location relative to the plant effectively affect the efficiency of trapping and are related to the height of the vegetation cover. On the other hand, Bloem and Spaltenstein (2011) showed that when light traps are used to control *T. absoluta* in tomato fields in Italy, the height of the light trap should not exceed 100 cm above the soil surface. Caparros Megido *et al.* (2013) reported that traps up to 60 cm high capture significantly more moths than traps located at higher altitudes, regardless of the stage of plant development.

According to Figure (3), the traps placed at a height of 70 cm were responsible for catching70% of all the moths captured in this experiment. This means that the flight behavior of the moths is preferred at the height of the canopy of tomato plants

70 cm and decreases significantly as the height increases of the trap (Aksoy and Kovanci, 2016).

Trap types experiment.

As the tomato leaf miner is a nocturnal insect, attracted to light and based on those mentioned above, we developed our new trap and named it Good Luck Tuta (GLT) trap which combined white light, pheromone, and adhesive material and installed at a height of 70 cm. This combination has all the features that attract this pest. Therefore, it was necessary to evaluate the efficiency of this trap compared to the most common pheromone traps, which are the delta trap and the water trap.

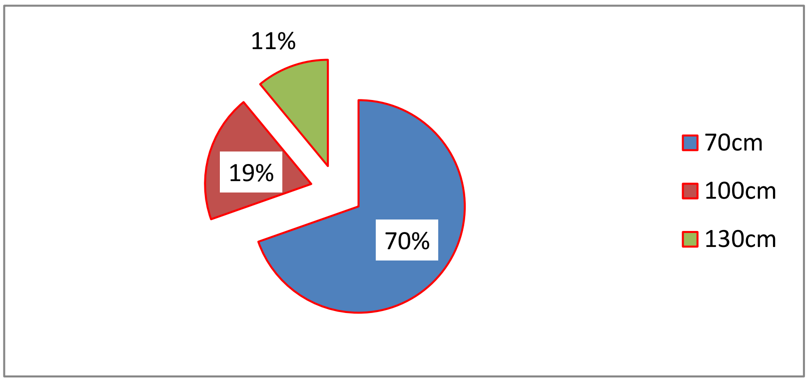

Figure (3): the percentages of the tomato leaf miners captured by the different heights traps in 7 days.

The total number of *T. absoluta* moths caught in all traps examined was 4934 moths/ 9 traps/ 9 days. The statistical analysis in Table (4) showed the largest number of moths were captured after 9 days followed by after 7 days of trapping by the GLT trap as 850.7 and 738.3 moth/trap respectively, while the number of moths captured after 5 days (599.3 moths) significantly did not differ from the number of moths captured by delta trap after 9 days (609.3 moths). The water trap captured the lowest number of moths after one day of trapping, with 60.3 moths per trap, and this number did not significantly differ from the number of moths captured after 3, 5, 7, and 9 days, which were 110, 145, 167.7, and 184.7, respectively. In terms of the daily mean of moths captured across all trap types, the highest number of moths was captured after 9 days of trapping, followed by 7 days of trapping, with 548.2 and 484 moths per trap, respectively. Conversely, the lowest number of moths was captured after one day of trapping, with 157.3 moths per trap, and this number significantly differed from the number of moths captured after 3 and 5 days, which were 299.8 and 398.3 moths per trap, respectively.

The GLT trap showed clear superiority over the delta and water trap Table (4). The average number of moths captured by the GLT trap after nine days was 581.4 months and differed significantly from the delta trap and water trap as 417.7 and 133.5 moths, respectively.

Figure (4) shows that the GLT trap captured 1.4 and 4.7 times more than the delta trap and water trap respectively. While the delta traps captured 3.4 times more than the water traps. This is due to the fact that the water trap does not capture all the males that are attracted to it, but only those that fall into the water. In other words, for every three attracted males, only one is caught in water trap (37% delta trap vs. 11% water trap capture).

Table (4): Effect of traps, days and their interactions on the cumulative number of tomato leaf miner moth.

Days	Number of tomato leaf miner moth			Means of days
	Water trap	Delta trap	GLT trap	
1	60.3 f	158.3 ef	253.3 ef	157.3 d
3	110.0 f	324.0 de	465.3 cd	299.8 c
5	145.0 ef	450.7 cd	599.3 bc	398.3 bc
7	167.7 ef	546.0 c	738.3 ab	484 ab
9	184.7 ef	609.3 bc	850.7 a	548.2 a
Mean of traps	133.5 c	417.7 b	581.4 a	

Means followed by same letter within each case are not differ significantly according to DMRT ≤ 0.05 Caparros Megido *et al*. (2013) indicated that the trap type is one of the main factors that influence the response of tomato leaf miner to traps.

These results were harmonious with the findings of Aksoy and Kovanci (2016) who reported that the delta traps captured 3.9 times more than the water traps. On the other hand, the superiority of the GLT trap over other trap types is due to its ability to capture males willing and unwilling to mate and able to mate more than once (Mirza 2014). In addition, it captured females that are in the egg-laying period, this is in line with Ardeh *et al*. (2021) findings, who showed that light traps capture females. Thus, the GLT trap don't give the females that succeeded in mating a chance for eggs laying.

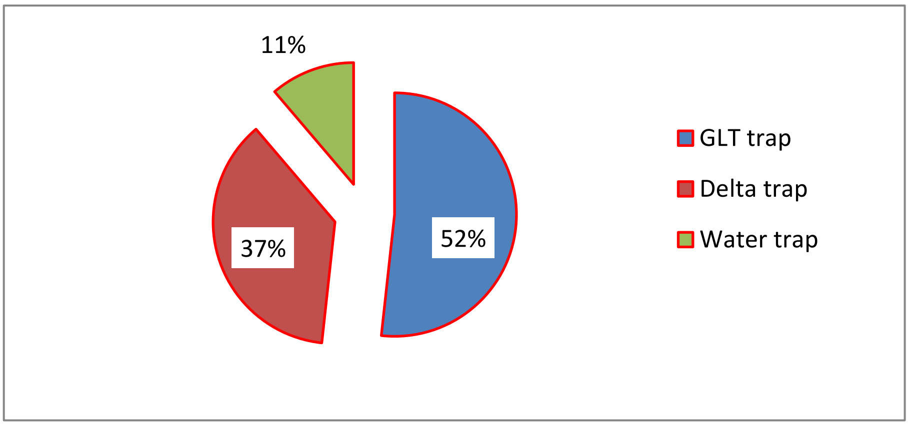

Figure (4): Percentages of tomato leaf moths that were caught by different traps.

While, the pheromone traps did not affect females mated previously, additions to that some females are capable of reproducing parthenogenetically (Illakwahhi and Srivastava, 2017). Aksoy and Kovanci (2016) indicated that light traps capture both males and females. Interestingly, this trap caught other harmful pests that were not within the scope of this study, such as cotton leafworm, tomato fruitworm, and tomato leaf miner fly.

The results revealed that the average number of insects captured by the GLT trap after one day was duplicated the number captured after 9 days of trapping (253.3 vs. 112.3) Figure (5). This rapid decline in the moth population when using the GLT trap is particularly noteworthy when compared to the findings of Vacas *et al*. (2011), who reported a period of 4 months to achieve effective control of *T. absoluta* using pheromone application. Cocco *et al.* (2012) showed that despite the higher number of captured males, the pheromone traps strategy was significantly not effective in reducing *T. absoluta* invasion. Assaf *et al.*, (2015) reported that the maximum number of males captured using pheromone traps was 1205.40/ trap/ week in the Kurdistan region- Iraq.

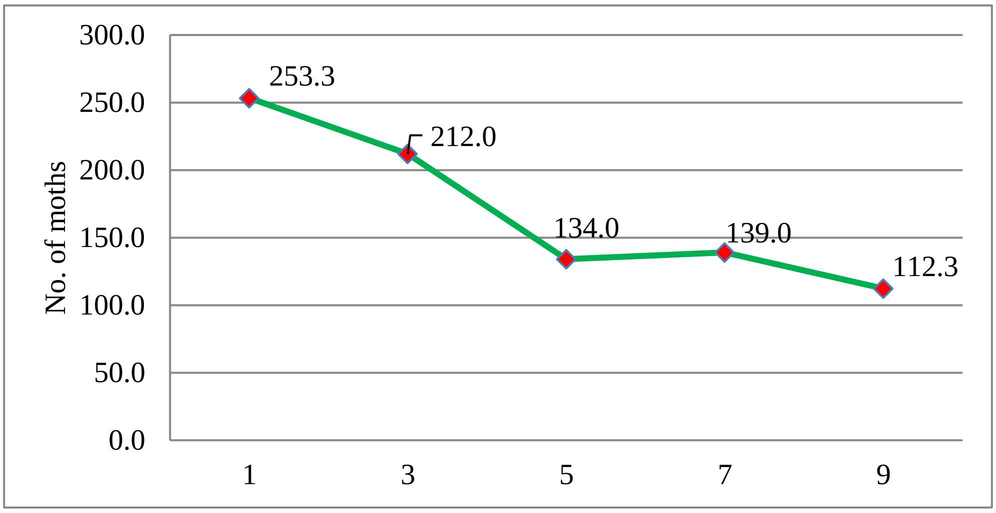

Figure (5): Decline in the daily rate of insects caught by GLT within nine days

CONCLUSIONS

The GLT trap is a promising way to manage this pest in infested fields in a short period. In addition, it is an inexpensive, effective, and homemade method without negative consequences. However, more studies need to be done, such as the density of traps per hectare and converting electrical energy sources to solar energy to suit open field conditions. Depending on the preferred flight high of *T. absoluta,* which was 70cm (50-70cm tomato canopy height), planting rows of crops with a height of more than 2 meters, such as broom corn or any other plant as insulators between open tomato fields, greatly reduces or hinders the possibility of the tomato leaf miner moving from an infected area to healthy once.

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CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest with the publication of this work.

كفاءة أنواع مختلفة من المصائد في جذب عثة اوراق الطماطم *Tuta absoluta* في ظروف الحقل

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الخلاصة

أجريت الدراسة في منطقة شاريا– دهوك/ اقليم كردستان العراق، لتقييم كفاءة المصائد الضوئية الصفراء والبيضاء والخضراء والزرقاء والحمراء، وثلاثة مستويات مختلفة (70 و100 و130 سم)، وثلاثة أنواع من المصائد (مصيدة دلتا، مصيدة مائية ومصيدة جديدة مزودة بالضوء ومادة لزجة والفيرومون، سميت بمصيدة GLT) في جذب عثة اوراق الطماطة. أثبتت النتائج ان المصائد الضوئية البيضاء كانت أكثر جاذبية وبشكل ملحوظ لعثة أوراق الطماطم، اذ جذبت 32٪ من العدد الإجمالي، يليه المصائد الضوئية الصفراء ومن ثم الزرقاء والخضراء والحمراء بمتوسط جذب (27، 22، 13، 6٪) على التوالي. جذبت المصائد الضوئية البيضاء المثبتة على ارتفاع 70 سم على اعلى نسبة مئوية لأعداد الحشرات المصطادة اذ بلغت 70٪ من العدد الإجمالي، واختلفت إحصائيًا عن المصائد المثبتة على ارتفاع 100 و130 سم، والتي جذبت 19 و11٪ على التوالي، بمعنى اخر أن نشاط طيران للعثة يتركز عند مستوى مظلة النبات. أثبت مصيدة GLT تفوقه الملحوظ على الأنواع الأخرى، اذ اصطادت 52٪ من العدد الإجمالي للعث الذي تم اصطياده، واختلفت احصائيا وبشكل معنوي عن مصيدة دلتا والمصيدة المائية (37 و11٪) على التوالي. كخطوة إضافية نحو استغلال سلوكية الآفة لإدارتها بدلاً من الاعتماد فقط على المكافحة الكيميائية. فان مصيدة (GLT) هو طريقة واعدة للسيطرة على الآفة في الحقول الموبوءة وفي فترة زمنية قصيرة.

الكلمات المفتاحية: مكافحة الآفات، المصائد الضوئية، الفرمون، توتا ابسليوتا، مصائد الماء.

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