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Original Article

Effectiveness of Various Solar Light Traps With and Without Sex Pheromone for Mass Trapping of Tomato Leaf Miner (*Tuta absoluta*) in a Tomato Field

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Abstract

Tuta absolute was a quarantine pest in Iran that has been recorded for the first time in 2009. The most conventional methods for control of this pest in Iran are chemical methods and mass trapping, although the efficiency of the latter method is not clear. In 2013, the efficiency of three common types of solar light traps with and without sex pheromone, along with water pan pheromone traps for control, were investigated. The experiment was performed in a randomized complete block design within in a tomato field. The treatments were Behroyan light trap (BL), Zist bani light trap (ZL), Russell light trap (RL), BL + pheromone, ZL+ pheromone, RL+ pheromone and water pan pheromone trap (WPT). Traps were checked weekly and the number of captured tomato leaf miner (TLM), Noctuid moths, *Chrysopa* sp., *Coccinella septempuctata* and Syrphid flies were counted. Mean weekly capture of TLM in BL, ZL and RL traps without sex pheromone were 9.11 ± 1.16, 4.94 ± 0.24 and 1.66 ± 0.7, while within traps sex pheromone were 54.72 ± 11.8, 42.05 ± 6.47, 39.02 ± 2.82, respectively. The mean weekly capture of Noctuid moths in the traps without pheromone were 16.92 ± 1.39, 25.39 ± 0.57, 1.49 ± 0.27 and with pheromone were 21.04 ± 1.72, 28.09 ± 0.95, 2.76 ± 1.39, respectively. Mean weekly capture of TLM and Noctuid moths in WPT traps were 47.13 ± 3.06 and 0.73 ± 0.27, respectively. The total attracted numbers of predators by the three light traps were not significant. In conclusion, traps baited sex pheromone (especially BL and ZL) could be used as eco- friendly tools for mass trapping of TLM and some key Noctuid moth pests in isolated tomato fields.

Keywords: light traps; noctuid moths; predators; quarantine pest; water pan traps

Introduction

Tomato, *Solanum lycopersicum* L., is one of the most popular vegetable crops in Iran .It is widely grown both in open fields and greenhouses. Tomato fruit is rich in nutrients such as vitamins, minerals and antioxidants. According to Ministry of Agriculture report of 2013 - 2014, 6.24 million tons of tomato have been harvested from 158.2 thousands hectares of cultivated areas in Iran so that, Fars province with 14.5 percent of the total tomato production was placed in the first position (Anonymous, 2014).

Tomato is attacked by a wide range of arthropod pests. The most common pests on tomato in Iran are tomato fruit borer (*Helicoverpa armigera* Hubner), tomato army worms (*Spodoptera* spp.), cut worms (*Agrotis* spp.), white fly (*Bemisia tabaci* Gennodius), aphids (*Aphis* spp.), leaf miner (*Liriomyza trifolii* Burgess), two spotted spider mite (*Tetranychus urticae* Koch) (Khanjani, 2013) and tomato leaf miner moth (*Tuta absoluta* Meyrick) (Baniameri and Cheraghani, 2012).

Tuta abosluta (Lepidoptera: Gelechiidae) was first described in Peru in 1917 (Meyrick, 1917) and then spread rapidly in all of the tomato-producing areas (Urbaneja *et al*., 2007; Viggiani *et al*., 2009; Abdul Razzak *et al*., 2010; Desneux *et al*., 2010; Kilic, 2010). It was first recorded in 2010 from Urmia city, North West of Iran (Baniameri and Cheraghani, 2012), then rapidly spread in the majority of tomato producing areas and became one of the most important pests of tomato. *T. absoluta* is a major pest of processing and fresh tomatoes, both in greenhouse and open fields (Desneux *et al*., 2010). The damages of larvae feeding is through mining leaves, stems and buds, burrowing tunnels in the fruits that result in low marketability of fresh tomatoes and yield losses up to 90-100% (Vargas, 1970). The preferred host of this pest is tomato (*Solanum*

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lycopersicum L.), but it has also been recorded on potato (*Solanum tuberosum* L.), eggplant (*Solanum melongena* L.), tobacco (*Nicotiana tabacum* L.), bean (*Phaseoulus vulgaris* L.), pepino (*Solanum muricatum* Aiton), Cape gooseberry (*Physalis peruviana* L.) (Desneux *et al*., 2010) and some wild plants such as *Solanum nigrum* L., *Datura stramonium* L., *Lycium chinense* Mill. and *Malva* sp. (Pereyra and Sanchez, 2006; Desneux *et al*., 2010).

The control of *T. absoluta* is very challenging (Korycinska *et al*., 2009); chemical control is a common method to manage this pest (Galarza *et al*., 1984), but it has low efficiency (Cocco *et al*., 2013). Therefore, alternative and more environmental friendly control methods such as biological control (Torres *et al*., 2002; Gonzalez-Cabrera *et al*., 2011), mating disruption with sex pheromones (Carde 2007; Vacas *et al*., 2011; Cocco *et al*., 2012) and mass trapping by light traps (Oliveira *et al*., 2008; Emre and Orkun, 2016) and pheromone water pan traps (Emre and Orkun, 2016) have been proposed to control *T. absoluta*. The female sex pheromone of *T. absoluta* was identified in the late 1990s and pheromone blends were subsequently tested, aiming their use for field monitoring and mass trapping (Ferrara *et al*., 2001). The female sex pheromone is highly effective in attraction of male population of tomato leaf miners (Filho *et al*., 2000). For mass trapping, a high density of pheromone baited traps in strategic positions within a crop can be effective (Jones, 1998). Capturing a large numbers of male adults result in an imbalance in the pest sex ratio, this impacts the mating pattern of the pest (USDA APHIS, 2011). Hence, sex pheromone-based strategies are promising techniques to control this invasive pest (Hassan and Al-Zaidi, 2010).

In the present survey upon the management of *T. absoluta* mass trapping using various types of light traps with and without sex pheromone as a new control method in Iran was used. The main goals of the study were: (1) evaluating the efficiency of the three most conventional available solar light traps in Iran, with and without sex pheromone for mass trapping of *T. absoluta* in an open tomato field in Fars province; (2) determining the attractiveness of above mentioned traps for the important predators in tomato fields; and (3) determining the performance of the experimental traps for mass trapping of some important noctuid moths pests in tomato fields in order to production of organic yield.

Materials and Methods

Site of study

The study was carried out in spring and summer seasons (2013) in a tomato field of Baiza district (1995 m above sea level, 52° 43 'E and 29° 96′ N), locating at 35 km of Shiraz Northwest in Fars province (Iran). The experimental field was about 1.2 ha and about 600 m away from adjacent tomato fields and surrounded from South, West and East sides by vineyard orchards and from North side by area lacking (without) any vegetation. Tomato seeds ('Felat-e-Kimia' cultivar) were sown in the first half of April (2013) in rows distanced 1 meter. The farm was irrigated two or three times per week using tape irrigation system. Weeds were removed by hands twice in the whole growing season. Also, seedling were thinned manually and adjusted in rows with distance about 25-30 cm when they had 3-4 true leaves and maximum 7-8 cm height.

Traps and their arrangement in the field

Three of the most conventional solar LED light traps in Iran markets (Table 1), widely used for mass trapping of TLM and many of others moth pests (with and without the sex pheromone), along with water pan pheromone traps (control treatment) were arranged in a randomized complete design block with 7 treatments in three replicates. Each experimental plot was about 550 m^2.

The traps were: (1) Behroyan light trap; (2) Behroyan light trap baited sex pheromone; (3) Zist bani light trap; (4) Zist bani light trap baited sex pheromone; (5) Russell light trap; (6) Russell light trap baited sex pheromone and (7) water pan sex pheromone trap (control treatment). Behroyan and Zeist bani traps were manufactured in Iran but Russell light trap was imported from China. The important characters of the mentioned traps listed in Table 1.

All traps were charged automatically with sun light in day time and performed form sun set to 2 hours after mid night. Control treatment (water pan pheromone baited trap) had white water pan with 8 liter water capacity (Fig. 1) and baited with the same sex pheromone used in light traps. Although each trap had two pheromone baskets, only one sex pheromone of *T. absoluta* with 0.5 mg dose (Sanidad Agricola, Econec, Ltd, Spain) was used in any one of traps baited sex pheromone (12 traps baited with pheromone) and renewed after 6 weeks. Some drops of hand washing liquid were added in water pans of all traps for killing captured insects and reducing water evaporation (Chermiti and Abbes, 2012). Traps were refilled with water twice per week due to hot weather and high respiration in the region. The traps were placed in the middle of each plot in the field once tomato seedlings had maximum 6-7 cm height. They were placed at ground level in the field at the beginning stage of the experiment and gradually increased their height according to the growth stage of the tomato plants and finally fixed above the plants canopy (Ferrara *et al*., 2001).

Sampling methods

The traps were checked once or twice per week and the number of *T. absoluta* and noctuid moths (*Helicoverpa armigera*, *Spodoptera* spp., *Agrotis* sp., *etc*.), *Chrysopa carnea, C. septempunctata* L. and Syrphid flies were counted.

Table 1. The relevant characters of light traps used for mass trapping of *Tuta absoluta* in the experiment

Trap type	Number of lamps	pan color	Pan capacity (Lr)	Solar pan size (mm)	Producer
Zist bani	3	blue	10	40 × 40	Behroyan Pars Co. Shiraz, Iran
Behroyan	8	red	8	110 × 110	Zist Paya Co. Tehran, Iran
Russell	1	white	8	60 × 60	China

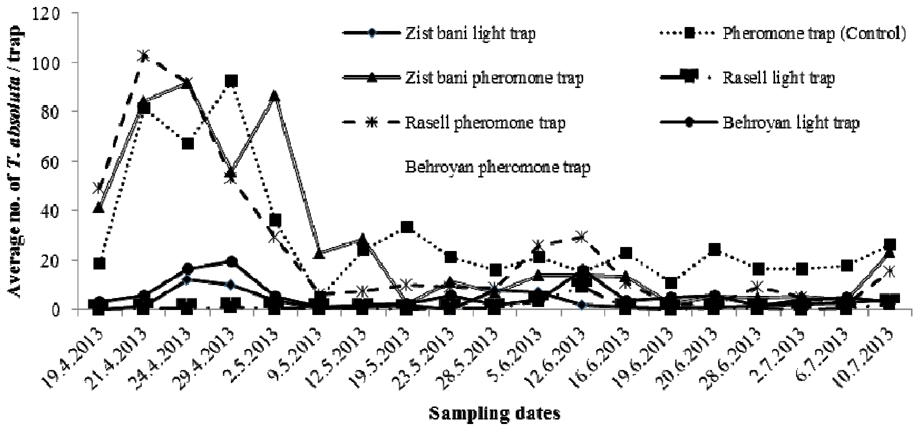

Fig. 1. Population fluctuations of *T. absoluta* in experimental tarps in various sampling dates

At harvesting time, 50 fruits were randomly collected from each plot and the number of infested and healthy fruit counted and the percentage of infested fruits in treatments was determined.

Statistical analysis

Data were evaluated through analysis of variance by using SAS software (version 9.1, SAS Institute, Cary, NC, USA) and mean comparisons of treatments were done with Duncan multiple tests ($\alpha \leq 0.01$). The population dynamics of *T. absoluta* and noctuid moths in traps in various sampling dates were determinated.

Results

Weekly capture of tomato leaf miner

Mean weekly capture adults of tomato leaf miner (TLM) showed significant differences among treatments ($F_{6, 12} = 58.51$; $P < 0.0001$; CV% = 17.78) at 0.01 percent probability level. The minimum weekly captured of TLM was observed in traps without sex pheromone, whereas the traps with sex pheromone had significantly higher captures of TLM than traps without sex pheromone (Table 2). All three light traps (without pheromone) were placed in the same statically group (c), while traps containing sex pheromone were placed in different statically groups. The maximum and minimum capture rate of TLM in traps containing sex pheromone were observed in Behroyan containing sex pheromone and Russell traps baited sex pheromone, respectively. There were no significant differences in average weekly capture of TLM between Behroyan traps containing sex pheromone (54.71 ± 1.18) and water pan pheromone traps (47.13 ± 3.06 adults). No significant differences were observed in average weekly capture of TLM in Zist bani traps containing sex pheromone (42.05 ± 6.47 adults) and Russell traps baited sex pheromone (39.02 ± 2.28 adults) .

Weekly capture of noctuid moths

The average weekly captured noctuid moths showed significant differences among treatments ($F_{6,12} = 63.57$; $P < 0.0001$; CV% = 18.71) at 0.01 percent probability level. The maximum weekly captured noctuid moths were observed in Zist bani traps with sex pheromone (28.9 ± 0.95). The minimum captured noctuid moths were observed in water pan pheromone traps (0.73 ± 0.27). There was no significant difference in the captured moths between water pan pheromone trap and Russell trap with pheromone (2.76 ± 0.57) and without pheromone (1.49 ± 0.27) (Table 2).

Weekly capture of Chrysopa carnea

Mean weekly capture of *C. carnea* in evaluated treatments were significant at 0.01 percent probability level ($F_{6,12} = 45.91$; $P < 0.0001$; CV% = 20.82).

Table 2. Mean weekly captured of *T. absoluta* adults and noctuid moths (mean ±SE) in experimental traps during whole growing season of tomato

Traps	Mean (+SE) weekly capture	
	T. absoluta	Noctuid moths
Behroyan light trap+ pheromone	54.72 ± 1.18 a	21.04 ± 1.72 bc
Behroyan light trap	9.11±1.16 c	16.92 ± 1.39 c
Zist bani light trap+ pheromone	42.05 ± 6.47 b	28.09 ± 0.95 a
Zist bani light trap	4.94 ± 0.24 c	25.39 ± 0.57 ab
Russell light trap+ pheromone	39.28 ± 2.28 b	2.76 ± 0.57 d
Russell light trap	1.66 ± 0.7 c	1,49 ± 0.27 d
Water pan pheromone trap	47.13 ± 3.06 ab	0.73 ± 0.27 d

* Means with same letters in each column are not significant at 0.01 percent of probability level according DMRT.

The maximum weekly capture of the investigated predator was observed in Behroyan light trap without pheromone (2.20 ± 0.11), whereas the minimum weekly capture was observed in water pan pheromone trap (0.06 ± 0.06) and Russell traps and with (0.33 ± 0.06) and without sex pheromone (0.20 ± 0.11), respectively. Although capture rate of *C. carnea* in Zeist bani trap with pheromone (1.33 ± 0.06) were higher than within the same trap without pheromone (1.02 ± 0.11), there was no significant difference between both of them (Table 3).

Weekly capture of syrphid flies

Significant differences were observed in weekly capture of syrphid flies among treatments at 0.01 percent probability level ($F_{6,12} = 102.75$; $P < 0.0001$; CV% = 27.34). The maximum weekly capture of syrphid flies were observed in Zist bani light trap with pheromone (5.73 ± 0.46) and without pheromone (5.46 ± 0.40), respectively while the other traps captured the minimum number of syrphid flies and all were placed in same statically group (b) (Table 3).

Weekly capture of Coccinella septempunctata

Significant differences were observed in capture rate of *C. septempunctata* among treatments at 0.01 percent probability level ($F_{6,12} = 43.34$; $P < 0.0001$; CV% = 18.84). The maximum and minimum weekly capture of this predator were observed in Zist bani trap without pheromone (1.04 ± 0.05) and water pan pheromone trap (zero capture), respectively. Capture rate of *C. septempunctata* in Behroyan traps with (0.29 ± 0.06) and without sex pheromone (0.29 ± 0.05) were not significant and both traps were placed in the same statically group (d). As well as, capture rate of *C. septempunctata* in Russell traps with pheromone (0.5 ± 0.02) and without pheromone (0.44 ± 0.04) were not significant and both traps were placed in the same statically group (c) (Table 3).

Population fluctuations of tomato leaf miner

The maximum population densities of *T. absoluta* were observed in the first of five sampling dates (in the other hand, ten days after trap placed in the field). Then, the population gradually decreased and was placed in the relatively constant level in the rest of the sampling dates (Fig. 2). The average capture rate of *T. absoluta* over growing the season in traps containing sex pheromone and light traps (without pheromone) were 10.6 and 1.09 adults/trap/night, respectively.

TLM density in the 1st, 2nd and 3rd sampling dates in traps containing sex pheromone were 23.04, 44.04 and 43.83 adults/trap/night, respectively. Afterwards, capture rate rapidly decreased and from the 6th sampling date (09.05.2013) onwards, the trend was placed in the relatively constant level (3.32 adults/trap/nightly) (Fig. 3). In total, capture rate of TLM in light traps was very low in comparison to traps baited sex pheromone. The maximum capture rate in light traps was observed in the in the 3rd (4.83 adults/trap/nightly) and the 4th sampling dates (5.05 adults/trap/nightly), while capture rate in the other sampling dates were low (in average 0.57 adult /trap /night) (Fig. 3). Figs. 2 and 3 show the same TLM population pattern in the experimental field.

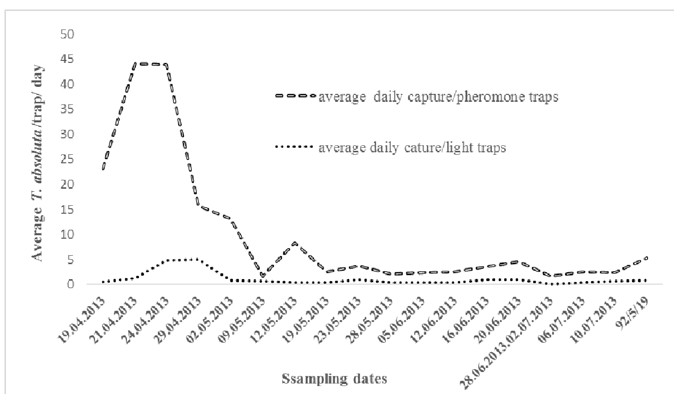

Fig. 2. Population fluctuations of *T. absoluta* adults in traps containing sex pheromone and traps lacking sex pheromone (light traps) in a tomato field

Table 3. Mean weekly captured of *Chrysopa carnea, Coccinella septempunctata* and Syrphid flies (Mean ±SE) in experimental traps during whole growing season of tomato

Traps	Mean (+SE) weekly capture rate of predators		
	Chrysopa carnea	*Coccinella septempunctata*	Syrphid flies
Behroyan light trap+ pheromone	1.6 ± 0.2 b	0.29 ± 0.06 d	0.2 ± 0.11 b
Behroyan light trap	2.2 ± 011 a	0.29 ± 0.05 d	0.2 ± 0.2 b
Zist bani light trap+ pheromone	1.3 ± 0.06 bc	0.75 ± 0.08 b	5.7 ± 0.46 a
Zist bani light trap	1.2 ± 0.11 c	1.04 ± 0.05 a	5.46 ± 0.40 a
Russell light trap+ pheromone	0.33 ± 0.06 d	0.05 ± 0.02 cd	013 ± 0.6 b
Russell light trap	0.2 ± 0.11 d	0.44 ± 0.04 c	0.000 b
Water pan pheromone trap	0.06 ± 0.06 d	0.000 e	0.000 b

Means with same letters in each column are not significant at 0.01 percent of probability level according DMRT.

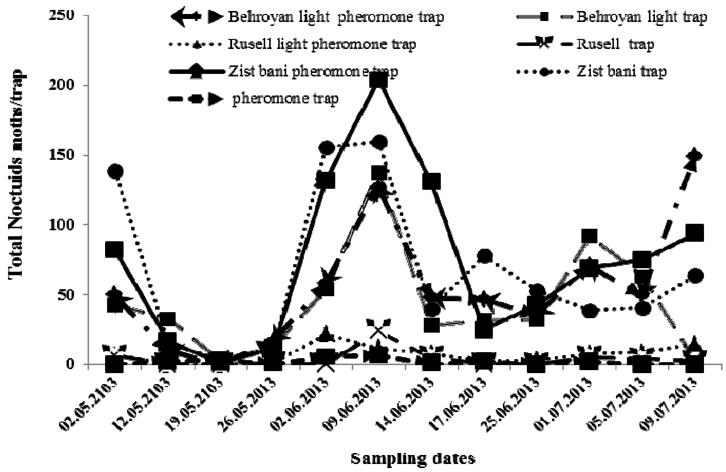

Fig. 3. Population fluctuations of noctuid moths in various traps in different sampling dates

Population fluctuations of noctuid moths

As shown in Fig. 3, the population peak of noctuid moths in various sampling dates was observed between 2013.05.26 and 2013.06.17 and all traps had the same pattern in this period. The most important captured moths were *Spodoptera* spp., *Agrotis* spp. and *Helicoverpa armigera*. In the most sampling dates, Zist bani traps with and without sex pheromone captured the maximums number of the moths, followed by Behroyan with and without pheromone traps. The capture rates of the moths by Russell trap with and without pheromone were low.

Discussion

Results showed that the performance of traps baited sex pheromone were 9 times (45.73 ± 6.86 moths/trap/week) higher than traps lacking pheromone (5.23 ± 3.78 moths/trap/week). In the other hand, 92% of the 7,152 adults of all captured TLM were (21 traps) captured by traps containing sex pheromone (9 light - pheromone traps +3 water pan traps) and 8% by traps lacking sex pheromone (9 light traps).

There are many factors affecting the efficiency of trapping system. Some factors are under the control of researchers and can be manipulated by them, including trap design (size, color and shape), attractant characteristics (source, composition, life span, dose and replacement time), trap position (height, position with respect to vegetation and trap density), pest and natural enemies and their population densities (Uchôa-Fernandes *et al.*, 1994; Howse, 1998; Ferrara *et al.*, 2001, Salas, 2004; Silva, 2008; Bolckmans, 2009; Abbes *et al.*, 2011, Chermiti and Abbes, 2012; Caparros Megido *et al.*, 2013), whereas other factors such as moon light and weather condition (temperature, relative humidity, wind, rain) are not generally under the control of researchers and cannot be manipulated directly (McGeachie, 1989; Yela and Holyoak, 1997; Holloway *et al.*, 2001). Besides the above mentioned factors, parthenogenesis in adult females (Caparros Megido *et al.*, 2013) and polygenic in adult males (Silva, 2008) are others important factors affecting the mass trapping performances of *T. absoluta*.

In the present experiment, not only the attractant type (light, pheromone or combination of light and pheromone) had the main role on traps efficiency, but also using some of the recommended key points in literatures for maximizing traps' efficiency, useful in taking successful results. For instance, **(1)** an isolated tomato field was selected as experimental place because the isolation of the tomato fields reduces the rate of adults immigration particularly the fertilized females from adjacent fields within the experimental fields and increase the efficiency of mass trapping system (Harbi *et al.*, 2012; Caparros Megido *et al.*, 2013). **(2)** All traps were placed at ground levels in the early growth stage of tomato plants (seedlings had maximum 10 centimeter height and 3-4 leaves) and gradually trap height was adjusted according to the growth stage of the tomato plants. Literatures showed that mass trapping experiments were often successful in areas with low to medium pest population (Silva, 2008; Vacas *et al.*, 2011; Cocco *et al.*, 2012). For successful mass trapping programs, traps must be deployed early in the plant growth cycle, when *T. absoluta* populations are present at low densities (El-Sayed *et al.*, 2006). Also, the height of the trap in the crop influences males capture and is related to the height of the tomato plants (Uchôa-Fernandes *et al.*, 1994; Ferrara *et al.*, 2001). **(3)** Water pan traps were used in the experiment because they are easier to maintain and have a larger trapping capacity than Delta traps and also these traps are the most common pheromone traps used for mass trapping of *T. absoluta* (El-Sayed *et al.*, 2006). Of course, water pan traps needed frequent water refilling under hot weather conditions in the summer ((Emre and Orkun, 2016). **(4)** Pheromone capsule dispenser with standard dose (0.5 mg) was used to increase the attraction rate of the adult males. This dose were recommended as the standard dose in mass trap pining experiments of *T. absoluta* (El-Sayed *et al.*, 2006) in areas with low to medium pest population. **(5)** Sex pheromone dispenser in traps was replaced after 6 weeks as recommended by the manufactured company and the water solution inside the water pan traps were renewed before traps became saturated with the attracted insects. **(6)** All traps (21 traps) were uniformly distributed in the field with 23.5 m apart. Recent studies on the range of attraction of pheromone traps to some *Agrotis* species suggested that an estimated distance of 20 m between individual traps would be needed to permit substantial mass trapping (Sufyan *et al*., 2011).

There are many reasons for higher performance of traps containing sex pheromone than light traps: for instance, **(1)** sex pheromone are species-specific chemicals that are active in extremely low doses and play an important role in integrated pest management for structural, landscape, agricultural or forest pest (Riedl *et al*., 1976; Jones, 1998) while light is a visual attractant which attracts many insect species. In Europe, *Cydia pomonella*, *Eupoecilia ambiguella* and *Lobesia botrana* were successfully controlled using pheromone-based management techniques (Ridgway *et al*., 1990; Witzgall and Arn, 1997). **(2)** Attraction radius of sex pheromone is often more than light; therefore, traps containing sex pheromone are able to attract more insects from farther areas. Attraction radios were smaller than 30 meters in the most situations for 'normal' light sources in entomological research (Butler and Kondo, 1991; Muirhead-Thompson, 1991). **(3)** The performance of light traps is highly affected by unmanageable factors such as temperature, rainfall, wind speed, moonlight and cloud cover (Holyoak *et al*., 1997; Yela and Holyoak, 1997), but these factors have lower effects on sex pheromone traps. Generally, warm, moist and moonless nights produce highest specimen counts in light traps and conversely, the number of individuals caught in the light trap decreased as fullness of the moon increased, as well as, strong winds reduced light trap catches (Wallace, 1869).

Light traps have been widely used to control agricultural pests in developing countries such as China (Ma *et al*., 2009), India (Srivastava *et al*., 1992) and Brazil (Oliveira *et al*., 2008). In China, currently commercial light traps are being used by the Chinese Ministry of Agriculture to control agricultural pests over an area of more than 32 million ha in 30 provinces. Although there were no significant differences in the capture rate of *T. absoluta* in light traps lacking sex pheromone, capture rate in Behroyan light trap without sex pheromone was nearly twice than Zist bani and Russell traps without pheromone (Table 2). The higher performance of Behroyan trap with and without sex pheromone than Zist bani and Russell traps with and without sex pheromone, could be related to the factors like color of water pan trap, volume of water pan, wave length and the number of light lamps in traps. Color of water pan in Behroyan was red, but in Zist bani and Russell traps were blue and white, respectively. Investigation showed traps containing dark color (black, red, green and blue) attracted higher number of TLM males than lighter color traps (yellow and white). Also, the mean catch of *T. absoluta* moths per trap in an experiment in Egypt were estimated 35.88, 17.58, 12.33 and 10.71 for red , blue, green and yellow trap, respectively (Taha *et al*., 2012). Therefore, the current results are in agreement with the previous data.

Trap shape and size had important effects on traps catch size. The capacity of water pan in Behroyan trap were 10 liter, whereas in Zist bani and Russell water pan were about 8 liter, therefore, larger trapping capacity in Behroyan trap than Zist bani and Russell traps could be the another factor resulted in higher capture rate of this trap. The effective wavelengths and intensities vary among species (Yang *et al*., 2003). Wave length in Behroyan trap was reported as 400 nm by the manufactured company, but there was no information about wave length of Zist bani and Russell type light traps. Insects are sensitive to a broad spectrum of light ranging from ultraviolet (UV) to red (Stark and Tan, 1982). However, not all species are attracted to light to the same extent (Bowden, 1982; Butler *et al*., 1999), but Lepidoptera are strongly attracted to UV and blue color, with a peak atraction in about 400 nm wavelenghts (Cowan and Gries, 2009). Behroyan trap had 8 LED lamps, whereas Zist bani and Russell trap had one lamp in each trap. A number of light lamps had positive effects on attraction rate of insects because increased intensity of light is more effective than low-intensity light in attracting moths (Stremer, 1959).

As shown in Fig. 2, in the first ten days after traps installation in the field, TLM population in traps containing sex pheromone were higher (162.82 adult/traps/week) than action threshold (using insecticides) mentioned in some previous studies (Benvenga *et al*., 2007; Stole *et al*., 2009), but high performance of traps, specially traps baited sex pheromone, resulted in high reduction of TLM population (18.5 adult/ traps /week) and lowering the pest population under the action threshold in the rest period of tomato growing seasons (about 2 months).

Based on the number of adult's males of *T. absoluta* caught in pheromone traps, the risk of infestation will be low for 1 to 3 captured moth per week, moderate for 4 to 30 captured moth per week and high for more than 30 moths per week (Stol *et al*., 2009). However, mass trapping would likely be more effective when integrated with recommended insecticide, fortunately no insecticide was used in this study and fruits infestation rate at harvesting time were less than 5 percent. Using insecticides for management of *T. absoluta* is largely based on adult captures in sexual pheromone traps (Benvenga *et al*., 2007), as adult catches are correlated with larval damages and yield losses (Faccioli, 1993). In Brazil, economic threshold were determined as 45 ± 19.50 *T. absoluta* daily cached adults using pheromone traps (Benvenga *et al*., 2007), while in Chile, economic threshold were reported as 100 males per pheromone trap per day. The hereby results revealed that mass traping with traps baited sex pheromone could be an effective tools for mass traping of TLM. The results confirmed those of Emre and Orkan (2016) in Turkey. Mass trapping experiments of TLM have been successful in tomato fields with low pest population, isolated tomato fields and controlled spaces such as greenhouses (Filho *et al*., 2000; Vacas *et al*., 2011; Cocco *et al*., 2012, 2013).

In greenhouse condition, using at least one trap per 500 square meters, moth populations was significantly reduced as part of an integrated pest management program (Stoltman *et al*., 2010). In conclusion, traps baited with sex pheromones are absolutely necessary for effective mass trapping of *T. absoluta* in open tomato fields in Fars climatic condition. Also, timely placing of traps in the field, selection of isolated tomato fields, using water pan traps, using standard pheromone dispensers (at least 0.5 mg dose) and replacing of pheromone dispensers after two months will increase trap efficiency in mass traping programs of TLM.

As shown in Table 1, light traps captured a large number of the above mentioned moths because they are the most species-rich family in the Lepidoptera (Scoble, 1992) and usually comprise a larger proportion of captures in light and bait traps than any other family (White, 1991; Cowan and Gries, 2009). The maximum and minimum number of noctuid moths was captured by Zist bani and Russell traps respectively. *Helicoverpa armigera* Hübner, *Spodoptera* sp, *Agrotis* spp. were the main species captured by all light traps. They are the most important pests of tomato in Iran; among them, *Helicoverpa armigera* is the fruit borer with high potential of damaging, specially in the first generation (Khanjani, 2013). It is known that moth catches are significantly influenced by the type of trap, sampling mode, time of day, season and duration of sampling (Thomas and Thomas, 1994) and light sources employed and its spectral composition (Fayle *et al*., 2007). In addition, a range of a biotic factors affect the efficiency of light traps, such as temperature, rainfall, moonlight and cloud cover (Holyoak *et al*., 1997; Yela and Holyoake, 1997). In the present experiment, differences in noctuid moths captured in traps were related to factors like color of pans, number of lamps and traps wavelength. Trap color has been reported to be a significant factor affecting catches of several moth species (Childers *et al*., 1979; Mitchell *et al*., 1989). Color of water pan in Zist bani was blue, while in Behroyan and Russell were red and white, respectively. Also, the number of LED lamps in Zist bani was 3, whereas in Behroyan was 8 and Russell was 1. Yela and Holyoake (1997) claim that the most important factor affecting catch size in light traps is the light intensity, with more moths being caught at higher intensitie . In contrast, Williams (1951) found that a 125W ultraviolet bulb caught greater numbers of moths than a 200W standard bulb. Generally, each species has sets of wavelengths to which it is most attracted or repelled (Fayle *et al*., 2007). The wavelength in Behroyan was reported 400 nm, while in Zist bani and Russell trap were unknown. Ting *et al*. (1974) have reported that in the range of visible light, *H. armigera* (Hübner) and *H. assault*_Guenée exhibited strong attractiveness to the light of 405 nm.

Literatures showed a large numbers of non-target species especially beneficial insects are attracted and killed by light traps (Nabli *et al*., 1999; 2009), so that evaluating the potentially negative impacts of experimental light traps on the major predators existing in tomato fields were important for this study. Although significant differences were observed in the number of attracted predators (*C. carnea*, *C. septempunctata* and syrphid flies) among traps, the total numbers of attracted predators in three used light traps (with and without pheromone) were low. Therefore, all three light traps used in the experiment could be used as beneficial friendly tools for mass trapping of TLM. Li *et al*. (2015) showed various light traps including yellow light trap, black light trap, New Jersey light trap, UV light trap and CDC light trap attracted a low number of *Chrysopa* sp.

Nowadays, we can reduce the attraction rate of non-target insects, especially beneficial insects, by using artificial light traps containing special wavelength and color (Antignus, 2000; Duehl *et al*., 2012). LED solar light traps used in the current experiment were new types of light traps with selective wavelengths. Besides wavelength, trap color can also influence the attractiveness of light traps for natural enemies (Blackmer *et al*., 2008). In the hereby experiment, the maximum numbers of syrphid flies were attracted by Zist bani traps containing blue water pans, while the highest numbers of *Chrysopa* sp. were attracted by Behroyan light traps containing red water pans. The obtained results confirmed those of Rodriguez-Saona *et al*. (2012) in New Jersey (USA) and Hoback *et al.* (1999) in Maricopa in Arizona (USA). The maximum numbers of *C. septempunctata* were attracted by Zzist bani and Behroyan light traps, while the minimum number was observed in Russell traps with white water pans, whereas the total cached number of *C. septempunctata* by all three light traps were less than 200 ladybirds. On the basis of comparison of attraction rate to different wave lengths of light, ladybirds were most attracted to backlight traps (Nabile *et al*., 1999). In conclusion, some types of water pan light traps baited sex pheromone showed good potential for mass trapping and suppressing the populations of *T. absoluta* in the experimental fields.

Conclusions

For successful mass trapping of tomato leaf miner, the following key factors should be considered: 1) Proper placement of traps in the early growth stage of tomato plants (immediately after seed germination, in direct seed planting or after transplanting); 2) using isolated field for mass trapping; 3) proper trap density (at least one trap per 500 m^2); 4) using pheromone dispensers with proper dose (at least 0.5 mg dose) and 5) increasing trap height according to plant growth. The results show that Behroyan and Zist-bani light traps baited sex pheromones can be used as an effective and eco-friendly tool for mass trapping of *T. absolute*.

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