Biologia (2021) 76:1175–1188
https://doi.org/10.2478/s11756-020-00628-2

ORIGINAL ARTICLE

Effectiveness of mass trapping and *Trichogramma cacoeciae* (Hymenoptera: Trichogrammatidae) releases against *Ectomyelois ceratoniae* (Lepidoptera: Pyralidae) in Tunisian oases

Sahar Zougari[1,2,3] · Sabrine Attia[2] · Anis Zouba[3] · Kaouthar Lebdi-Grissa[2]

Received: 6 January 2020 / Accepted: 12 October 2020 / Published online: 16 November 2020

Abstract
This study was carried out to evaluate two biological methods for the control of *Ectomyelois ceratoniae* (Lepidoptera: Pyralidae) which is considered to be the most important pest species in Tunisia. Mass trapping through 14 traps (water and delta) baited with sex pheromone, and *Trichogramma cacoeciae* releases with two doses: 25,000 *Trichogramma* (T)/ha (D1) and 50,000 T/ha (D2) were tested separately. Field trials were conducted during 2016 in oases cultivated by date palm trees and pomegranates. In this experiment the infestation rates for delta traps, water traps and control were 17.6, 32.9 and 87.3%, respectively. Therefore, mass trapping with 14 delta traps was the most effective on pomegranate fruits. After inundative releases of *T. cacoeciae* (D1: 25,000 and D2: 50,000 T/ha), the results revealed an impact of this parasitoid in inhibiting carob moth eggs hatching, and a significant reduction of the infestation rate of pomegranate fruits between 19.1 and 22.7% for both doses compared to control plot with 87.3%. However, these trials (mass trapping and *Trichogramma* releases) applied on date palm trees were not sufficient to limit economic losses.

Keywords *Ectomyelois ceratoniae* · *Trichogramma cacoeciae* · Mass trapping; water traps · Delta traps · Oases

Introduction

The date palm sector occupies an important place in the agricultural field in Tunisia. In fact, the palm groves located in the oases of southern Tunisia cover a total area of nearly 56 million ha with 5.2 million trees in 2016 which makes this sector the second after the olive oil sector (Observatoire National de l'Agriculture 2018). Indeed, Tunisia participates in the world date export market by 18.2% of the total value of exports with $254 million (Observatoire National de l'Agriculture 2018). Besides, Tunisia has 31% of its date under organic production and there is a steadily increasing demand for organic foods (Hached 2019).

✉ Sahar Zougari
sahar.zougari@gmail.com

[1] Department of Biological Sciences, Faculty of Science of Tunis, University of Tunis El Manar, 20 street of Tolède, 2092 Tunis, Tunisia

[2] Department of Plant health and Environment, LR14AGR02 of Bioaggressors and Integrated Pest Management in Agriculture, National Agronomic Institute of Tunisia, University of Carthage, 43 street Charles Nicolle, 1082 Tunis, Tunisia

[3] Technical Centre of Dates, 4280 Kebili, Tunisia

Pomegranate, *Punica granatum* L., has been cultivated since antiquity (Evreinoff 1949). This tree is well distributed in Tunisia from north to south as well in the coastal or mountainous areas, as the oases, because it is well adapted to the limestone soils, lack of water and arid climate (Mars and Marrakchi 1999). However, this large area of pomegranate trees provides low production (Dhoubi and Jammazi 1993, 1996). In ancient oases in the south of Tunisia, the traditional method is to plant the palms trees combined with fruit trees such as pomegranates.

Despite the abundance of pomegranate and palm productions, these two crops face many phytosanitary problems including lepidopterans. The carob moth *Ectomyelois ceratoniae* Zeller, 1839 (Lepidoptera: Pyralidae) is one of the most important pests in its larval stage (Mediouni and Dhouibi 2007; Krenn 2010) and is recognized as economically damaging several agricultural crops in many parts of the world such as Iran (Shakeri 2004; Norouzi et al. 2008; Sobhani et al. 2015; Ahmadi et al. 2016), Kingdom of Saudi Arabia (Al Barty 2014), Turkey (Ozturk et al. 2011; Mamay et al. 2016), United States of America (Nay 2005; Vetter et al. 2006), and the Mediterranean region such as Spain (García-Martínez et al. 2017), Italy (De Stefani 1920), Morocco (Madkouri 1978; Bouka et al. 2001) and Algeria (Ouamane et al. 2017; Roumani et al. 2018). The carob moth has been reported

on 43 hosts from 18 plant families. Twenty-one of these plants are economically important as agricultural commodities, 15 are ornamental plants and seven can be considered having multiple uses. The vast majority of hosts are tree species, and the families with the most species attacked are the Fabaceae and the Rosaceae (Perring et al. 2016). The majority of damage caused by *E. ceratoniae* is due to fruit infestations (Norouzi et al. 2008; Sobhani et al. 2015; Ahmadi et al. 2016). This pest is commonly found in carobs *Ceratonia siliqua* (L.) (Gothilf 1984), pistachios *Pistacia vera (*L.) (Mehrnejad 1993), almonds *Prunus dulcis (*Mill) (Gothilf 1984), figs *Ficus carica (*L.) (Shakeri 1993), walnuts *Juglans nigra (*L.) (Balachowsky 1972), citrus *Citrus sinensis* (L.) (Gothilf 1984), dates *Phoenix dactylifera* (L.) (Echlin 1982) and pomegranates *Punica granatum* (L.) (Al-Izzi et al. 1985; Mamay et al. 2016). In Tunisia, this ubiquitous species is the most important insect on pomegranate fruits (Braham 2015), citrus (Hached et al. 2018) and date palms (Khoualdia et al. 1996).

In order to obtain stable or higher yields, the management of this pest is crucial. However, the control of *E. ceratoniae* in Tunisia relies heavily on applications of chemical pesticides such as Abamectine and Emamectine-benzoate, which is commonly used to control carob moth in citrus orchards (Hached et al. 2018). Although, the use of pesticides would yield benefits such as the highest efficacy in reducing the infestation rate of fruits (Fornasiero et al. 2017) and the specificity of active molecules (Napoleao et al. 2018), the intensive use of pesticides has led to resistance in many insect species (Bass et al. 2015; Dermauw et al. 2018), threat to non-target organisms such as predatory wasps (Barros et al. 2014), lacewings (Amarasekare et al. 2015), hoverflies (Basley et al. 2018), ground beetles (Sharavari et al. 2015) and spiders (Graf et al. 2019), and toxicity to human health and environment (Nicolopoulou et al. 2016; Kim et al. 2017).

Besides, many chemical products have been shown to act on the nervous and reproductive systems of humans (Grewal et al. 2017), causing problems into the future (Jayaraj et al. 2016; Mahmood et al. 2016). As we know, in many countries there are no plans to ban pesticides from fields and other areas. Therefore, technical, economic and environmental factors are forcing to adopt new sustainable methods and there has been an increasing interest in controlling carob moth by alternative control tactics such as biological control agents (Frank 2010). Mass trapping and *Trichogramma* releases seem to be good alternatives to control the carob moth without damaging the ecosystem (Mamay et al. 2016; Mehrjardy et al. 2016; Gagnon et al. 2017; Ouamane et al. 2017). In fact, mass trapping combined with sex pheromone of pest is being developed in greenhouses against the tomato pinworm *Tuta absoluta* Meyrick, 1917 (Abbes et al. 2012; Cherif et al. 2017), in citrus orchards against the mediterranean fruit fly *Ceratitis capitata* Wiedemann, 1824 (Harbi et al. 2018; Hafsi et al. 2015*)* and in pomegranate orchards against the carob moth *E. ceratoniae* (Dhouibi et al. 2016).

The parasitoid *Trichogramma cacoeciae* Marchal, 1927 is known as biocontrol agents of many pests including lepidopteran species in the world (Desneux 2010; Chailleux et al. 2013). In Tunisia, it is used frequently against *T. absoluta* and *E. ceratoniae.* The releases of about 20 to 30 females of *Trichogramma* per tomato plant in greenhouses and 25,000 *Trichogramma* (T)/ha proved to be effective in controlling tomato fields against *T. absoluta* (Cherif et al. 2018; Zouba et al. 2013) and 25,000 T/ha (Dhouibi et al. 2016) and 16,000 T/ha (Hached 2019) to control *E. ceratoniae* in citrus orchards.

The present work was undertaken to evaluate the efficiency of mass trapping of *E. ceratoniae* using two types of traps water and delta. Furthermore, we performed inundative releases of *T. cacoeciae* to reduce damage of the carob moth in organic date palm orchards in the south-west of Tunisia.

Materials and methods

Experimental plots

Experiments were conducted during 2016 in three organic orchards including pomegranates and date palms in Nefleyette region belonging to governorate of Tozeur located in the south-west of Tunisia. Each orchard had an area of 2 ha, with date palms spaced at 8 m within and between rows. A total of 120 palms of Deglet Nour variety and 35 of Tounsi cultivar of pomegranate trees/ha per orchard were planted since 1975. Two orchards were divided each into four plots with an area of 0.5 ha. Plots were separated from each other by palms as windbreaks to make sure that treatments did not reach the other plots. Control treatment was conducted in the third orchard with an area of 1 ha including pomegranate and date palm trees. Experimental orchards received no insecticide treatment during the release period.

Climatic conditions

Climate data were recorded from weather station located in Tozeur. This region has a desert climate with low precipitation; a maximum rainfall registered from 2 May 2016 until 30 October 2016 was 4.6 mm (Fig. 1). For the same period, the mean temperature as well as the relative humidity varied from 19.7 to 34.9 C° and 31.5 to 68.2%, respectively (Fig. 1).

Mass trapping

Mass trapping trails were tested in an area of 2 ha, both delta and water traps were used in this experiment with a density of 14 traps per ha. Therefore, the tested area was divided into four equivalent replications: (1) and (2) for water traps on pomegranates and date palm trees, (3) and (4) for delta traps

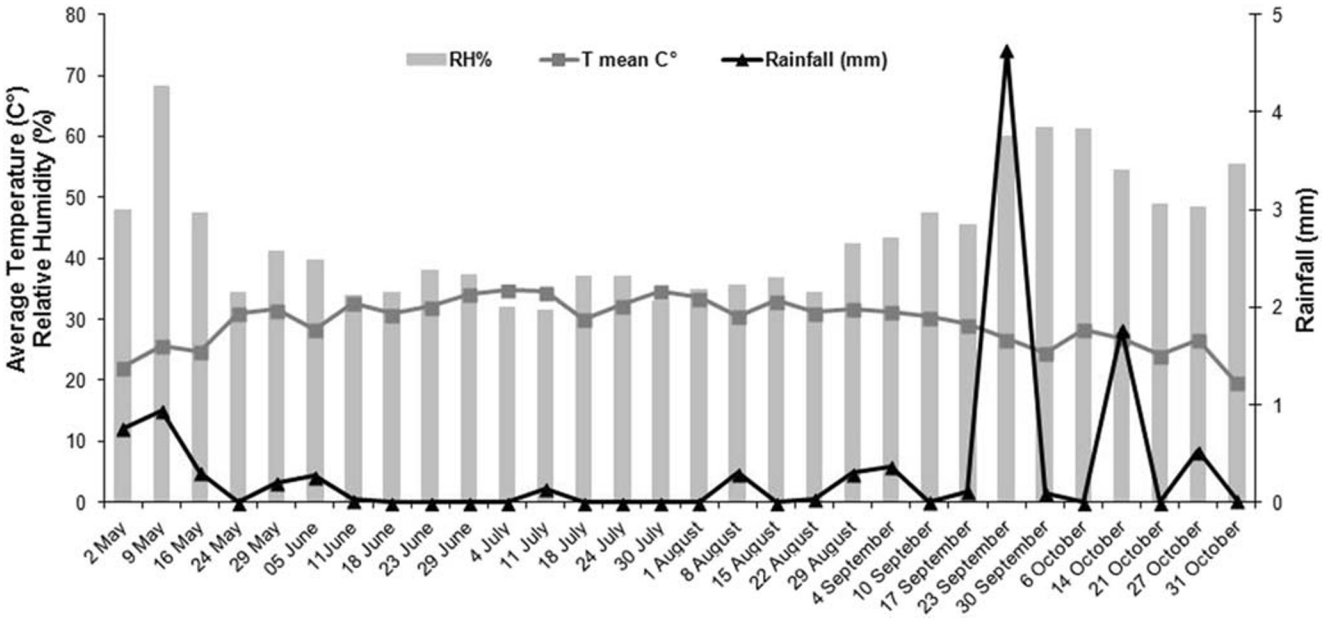

Fig. 1 Climograph of weekly mean temperature (C°), rainfall (mm) and relative humidity (%) during the monitoring period for *E. ceratoniae* in governorate of Tozeur (Tunisia) from 02 May until 31 October 2016

on pomegranate and date palm trees. Delta traps (ISCA) were composed of sticky cardboards 19.5 cm long, with a triangular cross-section of 10 × 10 × 10 cm and a 3 × 3 × 3 cm triangular entrance at each end; two of the three internal sides were coated with a sticky surface to retain trapped moths. Traps were stapled to a small tree trunk at a height of 1.5 m oriented in the same cardinal direction and checked once a week, the pheromone baits and sticky cardboards were changed with fresh ones every month.

A water trap used in this experiment was composed of a plastic recipient with a capacity of 2 L (21 × 15 × 8.5 cm) containing 1.5 L of water mixed with 30 ml of detergent and combined with sex pheromone of *E. ceratoniae* that was stapled to the trunk of the tree of each host plant.

Trichogramma releases

Releases tests were conducted in a 2 ha area. The parasitoid *T. cacoeciae* tested in the experiment has been already commercialized in Tunisia to control lepidopteran pests. Cardboards (5 × 1 cm^2) containing eggs of *Ephestia kuehniella* Zeller, 1879 parasitized by this parasitoid were provided by a private company (ControlMed, Tunisia). Four consecutive releases of *T. caccociae* spaced four weeks each were done. Two doses, 25,000 (D1) and 50,000 (D2) T/ha, were tested. The trial was conducted in four equivalent blocks containing each 60 date palm trees and 17 pomegranate trees (an area of 0.5 ha): (1) 25,000 T/ha for pomegranate trees, (2) corresponding to 25,000 on date palm trees, (3) 50,000 T/ha for pomegranate trees and (4) releases of 50,000 T/ha were done on date palm trees. A total of 50,000 and 100,000 T were released, respectively for D1 and D2 on 04/07, 05/08, 25/08 and 02/09 in 2016. For the four experimental plots one delta trap combined with sex pheromone of females of the carob moth was placed for monitoring of *E. ceratoniae* male flight.

In order to evaluate the efficacy of releases of *Trichogramma* in parasitizing *E. ceratoniae* eggs, a weekly sampling of 10 pomegranate fruits was done randomly from 4 July 2016 until 16 September 2016. Two hundred date fruits were collected randomly from five date palm trees from 2 September 2016 until 4 October in 2016. Then, samples were examined in the laboratory under binocular microscope (Leica® model MS5) to record the number of parasitized eggs of *E. ceratoniae*. To control the emergence rate of *Trichogramma*, after each release, 10 cardboards of 1000 T were taken randomly from each experimental plot and the numbers of hatched and unhatched eggs were counted. The emergence and parasitism rate were calculated according to the following formulas:

Emergence rate (%)=(number of hatched eggs of *E.kuehniella*/ total number of released eggs)*100

Parasitism rate (%)=(number of parasitized eggs of *E.ceratoniae*/ total number of eggs recorded)*100

Infestation by *E. ceratoniae*

Infestation rate was already determined on pomegranate and date palm fruits. The effectiveness of mass trapping through water and delta traps (with 14 traps/ha) and inundative releases of *T. cacoeciae* with the two doses 25,000 and 50,000 T/ha was determined by a weekly counting of the total

number of pomegranate fruits from five trees selected at the beginning of the experiments. Therefore, the total number as well as the number of infested fruits by *E. ceratoniae* was registered from 13 May 2016 until 16 September 2016. In addition, two-hundred date fruits/week/plot were collected randomly from five date palm trees from 2 September 2016 until 4 October 2016. All samples were examined under a binocular microscope in the laboratory. Every observed stage of *E. ceratoniae* referred to an infested fruit.

The reduction rate was calculated according to Abbott's formula as follows:

$$\textbf{Reductionrate} = [(A-B/A)*100]$$

A is the mean infestation of pomegranate and date fruits per week in control treatment and **B** is the mean infestation of pomegranate fruits per week in treated plot (Abbott 1925).

The infestation rate for both host plants was calculated according to the following formula:

$$\textbf{Infestation rate} = (N_A/N_B)\textbf{*100}$$

For pomegranate:

$\mathbf{N_A}$ is the number of infested pomegranate fruits per tree and $\mathbf{N_B}$ is the total number of pomegranate fruits per tree.

For date:

$\mathbf{N_A}$ is the number of infested fruits and $\mathbf{N_B}$ is the total number of fruits.

Statistical analyses

Graph pad Prism version was used to perform all statistical analysis. The obtained data corresponding to the parasitism rate of *E. ceratoniae* as well as the effectiveness of mass trapping and *T. cacoeciae* releases were subjected to repeated measures analysis of variance (GLM procedure). Additional one-way ANOVA followed by Tukey post hoc tests at $p = 0.05$ inside each treatment was carried out.

Results

Mass trapping in pomegranate and date palm orchards

Male catches on pomegranate trees

Catches data of *E. ceratoniae* males for both tested traps, water and delta traps, are presented in Fig. 2 and showed that during July and August the number of male catches was higher for delta traps compared with water traps. During the catching period, males started to appear with low density for the first two weeks with the two tested traps. Water and delta traps caught almost the same number of *E. ceratoniae* males. During the next period, the inspection of traps showed that water traps kept the same potential of catching moths, however, the catches of males through delta traps were higher compared with water traps. A total of 152 and 483 *E. ceratoniae* males/trap were caught by water and delta traps, respectively, with 14 traps/ha. The mean catches of the carob moth males reached 9.7 and 31.4 males/trap for water and delta traps, respectively (Fig. 3). Therefore, the assessment of trap catches showed a significant difference in capturing males between the two tested traps ($p = 0.0002$).

Male catches on date palm trees

In autumn-winter during maturity period, pheromone traps captured a total of 79 and 134 males/trap for water and delta traps, respectively. A maximum of captured males was recorded on 18 October with 16 and 27 males/trap for water and delta traps, respectively (Fig. 4). During the study period, the mean catches of males were significantly different between water and delta traps ($p = 0.0070$); they reached 11.3 and 19.1 males/trap for water and delta traps respectively (Fig. 5).

Mass trapping efficiency in reducing *E. ceratoniae* infestation on pomegranate and date palm fruits

Pomegranate fruits

Regular sampling of pomegranate fruits in the tested plots indicated that first infested fruit were recorded on 27 May 2016 and the percentage of infestation was about 3.8% in the control plot on the same date. However, our study showed that the percentages of attacked fruits were 0% for both trap types: water and sticky delta trap on the same date of sampling.

Infestation increased on 2 June 2016 to 2.5 and 2.7% for water and delta traps, respectively. Results showed that damages recorded on pomegranate fruits caused by *E. ceratoniae* were significantly different between the studied plots (water and delta trap plots) compared with the control ($F_{(2,\ 28)} = 17.77$; $p < 0.0001$) (Fig. 6). During harvest, control treatment showed maximum fruit infestation 87.3% compared with 32.9 and 17.6% for water and delta traps, respectively. Therefore, water and delta traps reduced the infestation caused by *E. ceratoniae* to 62.3 and 79.8%, respectively, compared with the untreated plot.

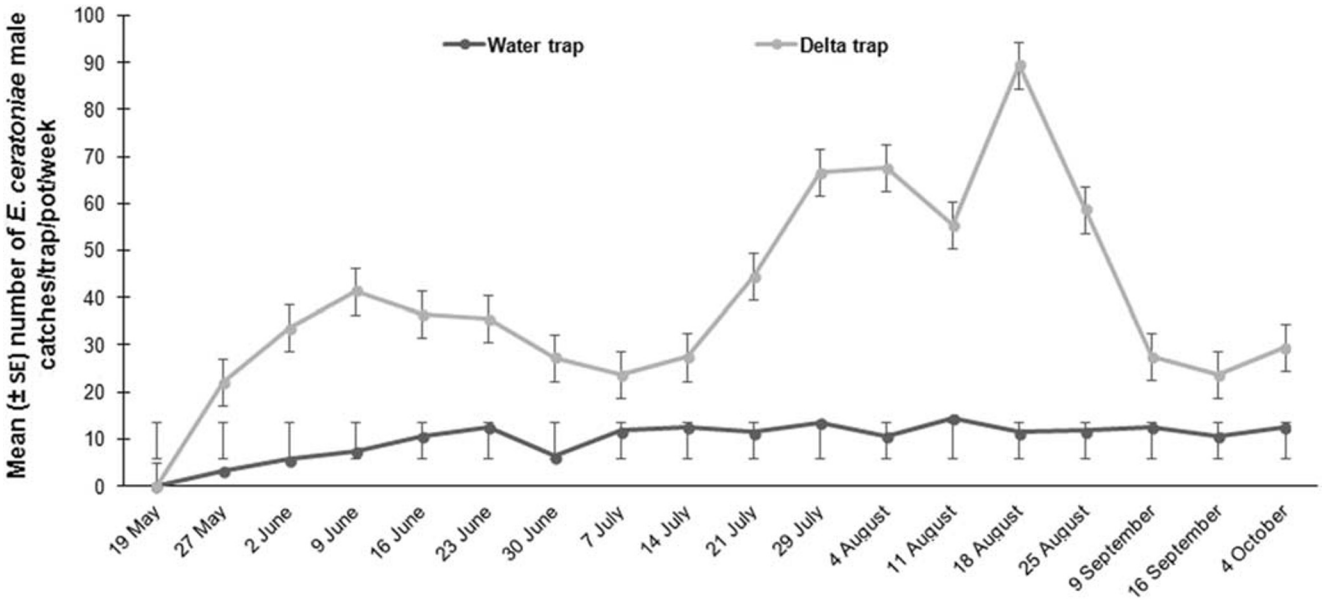

Fig. 2 Weekly catches of *E. ceratoniae* male per Water and Delta traps on pomegranate trees from 19 May until 04 October in Nefleyette oases during 2016

Date palm fruits

Contrary to pomegranate fruit results, the current experiment of mass trapping efficiency in reducing infestation caused by the carob moth on date palm fruit seem to be not satisfying. The regular sampling of 200 date palm fruits per week/plot from 2 September to 29 October 2016 (Fig. 7) showed that there was no significant difference between plots ($F_{(2,\ 4)} = 1.044$; $p = 0.4317$), the highest infestation of date fruits reached 24% in delta plot compared to 18.9 and 18.5% for water trap and control plot, respectively.

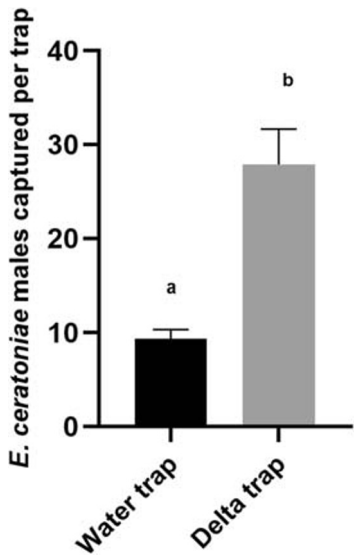

Fig. 3 Number of *E. ceratoniae* males captured per different trap types (Delta and Water traps) on pomegranate trees in Nefleyette oases during 2016. Different letters above the bars indicate significant differences ($p \leq 0.05$; Tukey's test)

Trichogramma releases

Emergence rate

Emergence rates of female *T. cacoeciae* from *E. kuehniella* eggs varied from 72.7 to 94.8% for both tested doses, 25,000 and 50,000 of T/ha, respectively. For both pomegranate and date palm trees emergence of *T. cacoeciae* was successful.

Male captures

Pomegranate

Results of male catches of *E. ceratoniae* through pheromone traps from 4 July 2016 until 9 September 2016 on pomegranate trees (Fig. 8) showed the presence of the pest during all the study period. For the first release we recorded 3, 5 and 6 males/trap for 25,000 (D1), 50,000 T/ha (D2) and control plots, respectively. A major peak of adult males of *E. ceratoniae* was registered during the third release of *Trichogramma* (29 August 2016) with 4, 3 and 16 males/trap for D1, D2 and control, respectively. Tukey's test showed a significant difference between the treated plots and control ($F_{(1.265,\ 10.12)} = 19.78$, $p = 0.0008$) and ANOVA test showed a similarity in capturing carob moth males after *Trichogramma* releases for both tested doses ($p = 0.8958$).

Date palm

From 2 September until 4 October 2016 we recorded lesser moth catches than captures on pomegranate trees (Fig. 9). Fluctuation of *E. ceratoniae* males showed maximum catches on 23 September 2016 with 4, 5 and 7 males/trap for D1, D2

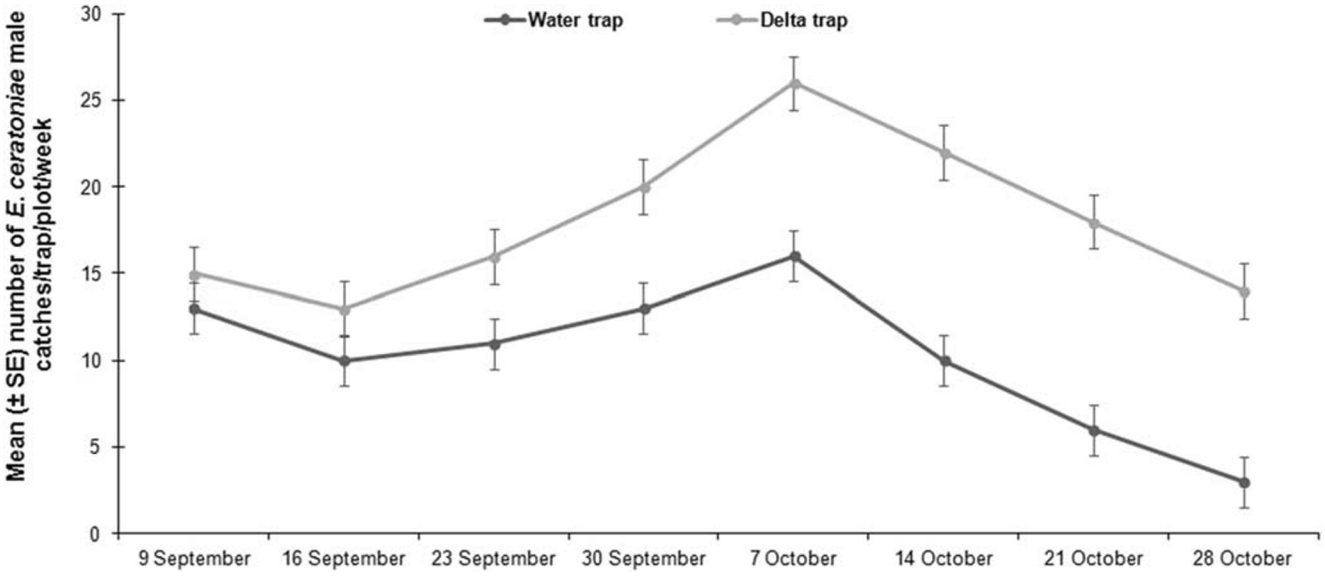

Fig. 4 Weekly catches of *E. ceratoniae* male per Water and Delta traps on date palm trees from 9 September until 29 October in Nefleyette oases during 2016

and control plots, respectively. ANOVA showed a significant difference between the different tested plots ($F_{(1.727,\ 6.907)} = 21$, $p = 0.0014$).

Parasitism rate

Pomegranate fruits

The presence of *E. ceratoniae* male moths in the target area was detected three days after fruit emergence, initiating the first release of *T. cacoeciae* in the experimental plots (D1 and D2).

A sample of 10 pomegranate fruits per tested plot was taken before *T. cacoeciae* release on 4 July 2016 and examined under binocular microscope. Results showed that this parasitoid was present in Nefleyette orchard with low density. Parasitism rate was about 3.9 and 6.1% of parasitized *E. ceratoniae* eggs (Fig. 10). Parasitism rate increased over the consecutive releases (after the second and third releases) for both tested doses. A maximum parasitism rate was recorded during the last release (3rd) in pomegranate fruits with 41.4% and 80.2% for 25,000 and 50,000 T/ha,

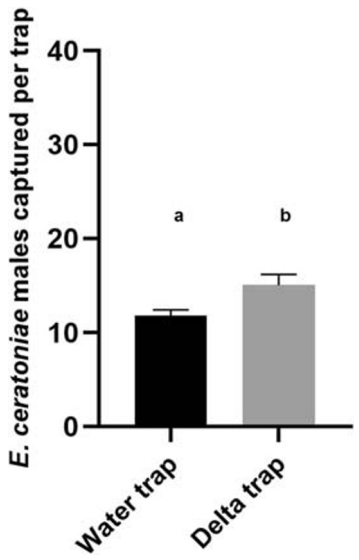

Fig. 5 Number of *E. ceratoniae* males captured per trap types (Delta and Water traps) on date palm trees in Nefleyette oases during 2016. Different letters above the bars indicate significant differences ($p \leq 0.05$; Tukey's test)

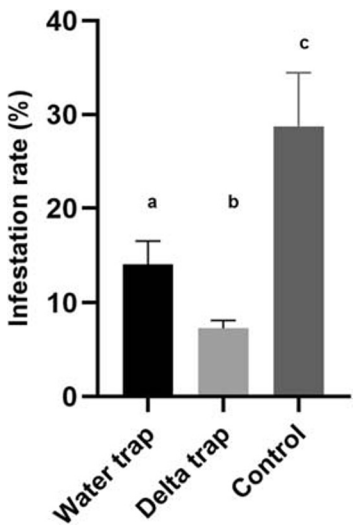

Fig. 6 Infestation rate of pomegranate fruits in Nefleyette oases during 2016. Different letters above the bars indicate significant differences ($p \leq 0.05$; Tukey's test)

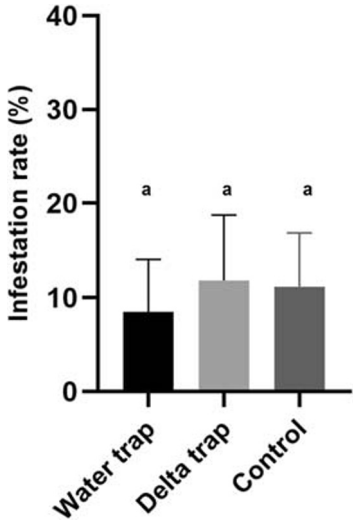

Fig. 7 Infestation rate of date palm fruits in Nefleyette oases during 2016. Different letters above the bars indicate significant differences ($p \leq 0.05$; Tukey's test)

respectively. Data analyses showed a p value of 0.0039 proving a significant difference between 25,000 and 50,000 T/ha releases in parasitizing carob moth eggs.

Date palm fruits

Samples of date fruits taken on 2 September 2016 showed 0% of parasitism of carob moth's eggs for each experimental plot. One week after *Trichogramma* release, maximum rate of parasitized eggs of carob moth was 6.7% for D1 compared to 18.3% for D2 (Fig. 11). There was no difference observed between 25,000 and 50,000 T/ha in parasitizing eggs of *E. ceratoniae.*

Infestation rate

After three releases of the parasitoid on pomegranate trees, a significant reduction in carob moth infestation on pomegranate fruits was observed between the treated and control plots ($F_{(1.006,\ 9.052)} = 25.93$, $p = 0.0006$). Nevertheless, no statistical difference was recorded between released doses ($p = 0.1557$) (Fig. 12a). Indeed, releases of D1 and D2 on date palm trees were not sufficient to reduce damages of date fruits ($F_{(1.06,\ 3.179)} = 0.3136$, $p = 0.6250$) (Fig. 12b). Pomegranate infestation increased over time, the highest infestation rate of fruits was recorded during harvest in control plot with 87.3% compared to 22.7 and 19.1% after *Trichogramma* release with the two tested doses D1 and D2, respectively. Therefore we registered a reduction rate of 74 and 78.1% for D1 and D2, respectively. The infestation rate is about 17.5 and 19% after release of 25,000 and 50,000 T/ha, respectively (Fig. 12b).

Discussion

Mass trapping

Male catches

This work showed a considerable capacity of capturing *E. ceratoniae* males through water and sticky delta traps in

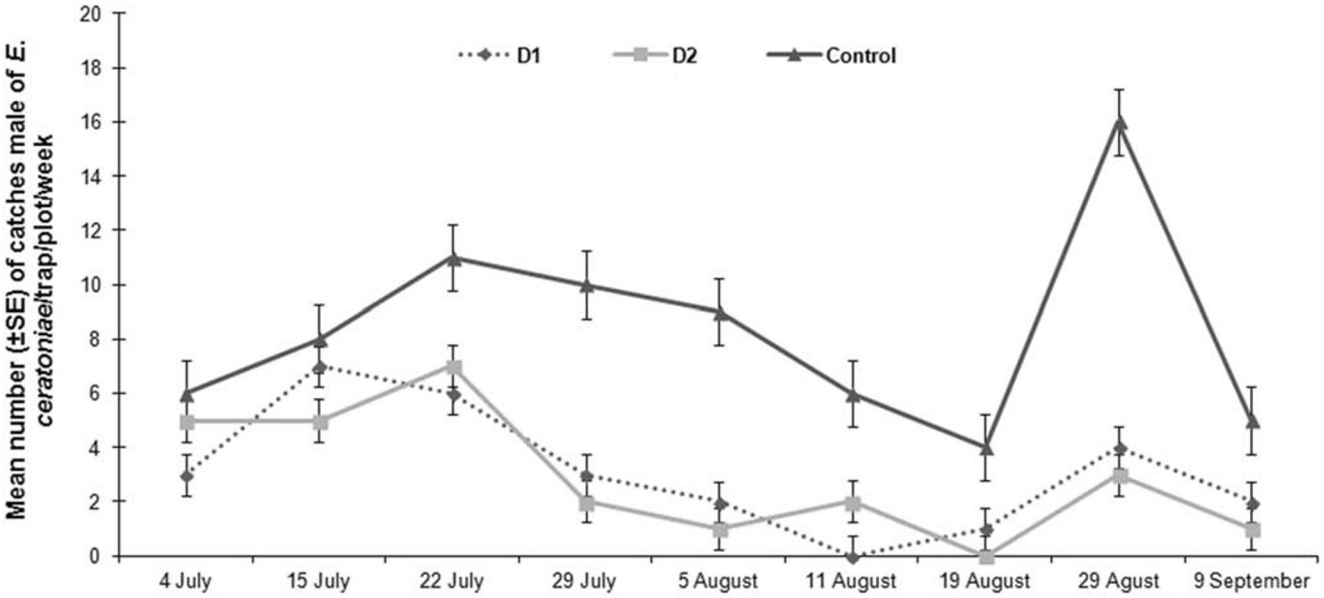

Fig. 8 Weekly captured males of *E. ceratoniae* in pomegranate plots after 25,000 T (D1) and 50,000 T (D2) releases during the period of study of 2016

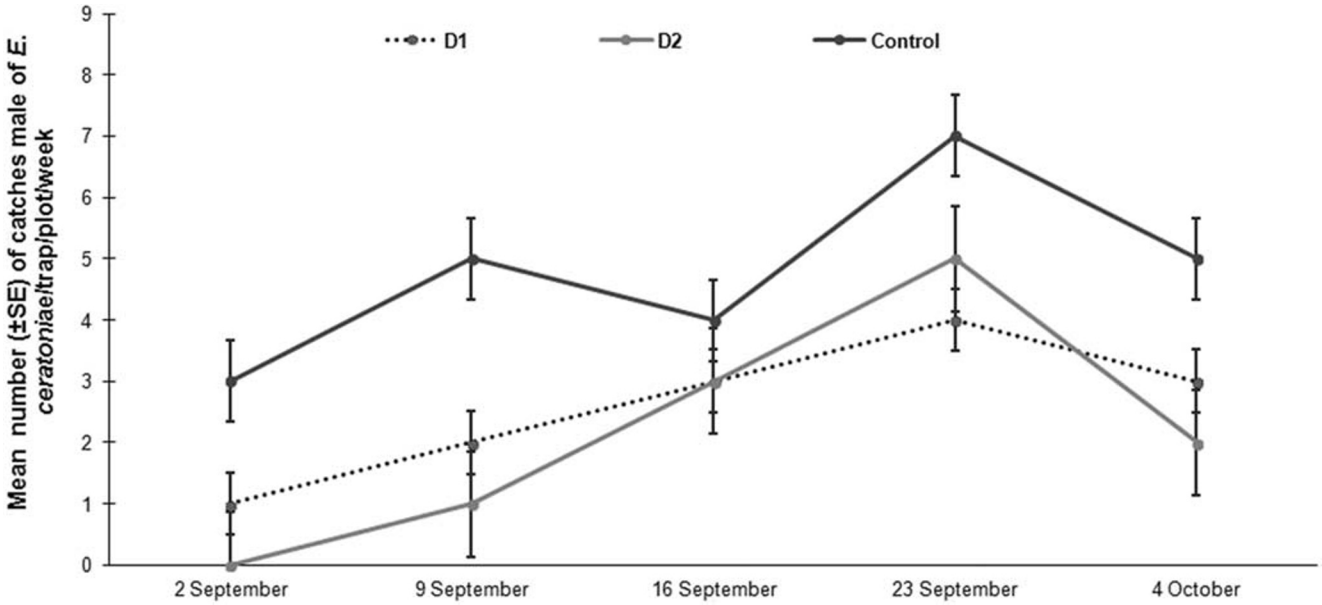

Fig. 9 Weekly captured males of *E. ceratoniae* in date palm plots after 25,000 T (D1) and 50,000 (D2) releases during 2016

Tozeur orchards from May until October 2016. Results showed that mass trapping requires the use of a highly efficient pheromone trap in order to remove most of the males before they encounter females and mate (El Sayed et al. 2006). Delta traps had captured significantly more males compared to water traps. A similar study was conducted in Iran, where Mehrjardy et al. (2016) showed that captured moths by the same type of traps, were 841 and 722 individuals in pomegranate and fig orchards, respectively. Several studies showed that delta traps were commonly used for controlling lepidopteran pests such as the codling moth, *Cydia pomonella* Linnaeus, 1758 (Willson and Trammel 1980; El Sayed et al. 2006), tomato leafminer *T. absoluta* (Aksoy and Kovanci 2016), lesser date moth *Batrachedra amydraula* Meyrick, 1916 (Levi-Zada et al. 2017) *Lobesia botrana* Denis & Schiffermüller, 1775 (Rayegan et al. 2016) and gypsy moth *Lymantria dispar* Linnaeus, 1758 (Charelton and Cardé 1990).

To our knowledge, no published literature was found on testing water traps to control *E. ceratoniae* on pomegranate and date palm orchards. The potential of male captures of *E. ceratoniae* by water traps can be reduced by the evaporation problem under hot weather conditions in the summer season, when temperature exceed 33 °C during July and August in the south west of Tunisia (Fig. 1). Chermiti and Abbes (2012) reported the effective use of large traps containing 5 L of water for mass trapping high populations of *T. absoluta* at a density of

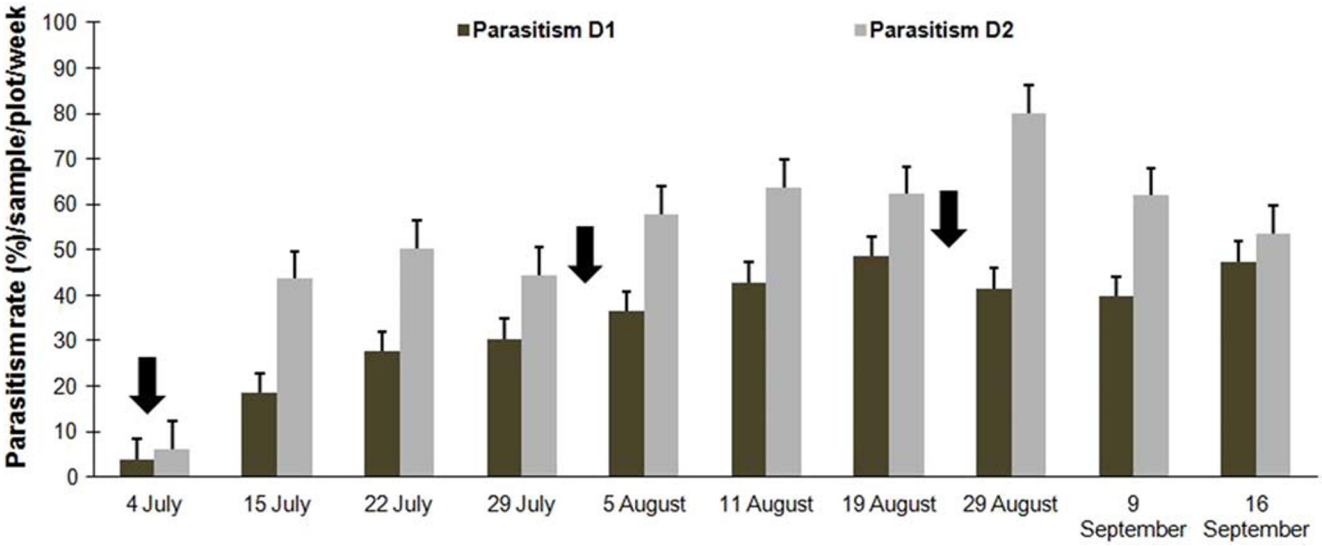

Fig. 10 Weekly parasitism rate of *E. ceratoniae* eggs after 25,000 (D1) and 50,000 (D2) T/ha releases on pomegranate trees in Nefleyette orchards during 2016. Arrows indicate release's date of *Trichogramma* for both tested doses

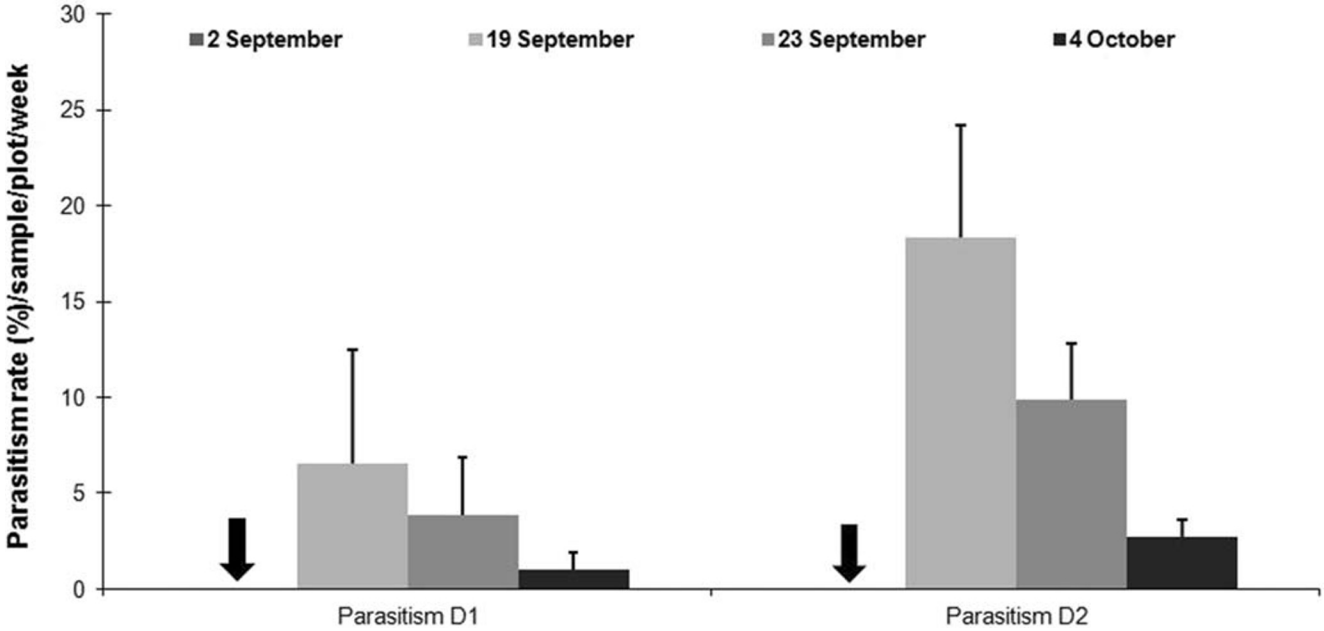

Fig. 11 Weekly parasitism rate of *E. ceratoniae* eggs after releases of 25,000 (D1) and 50,000 (D2) T/ha on date palm trees in Nefleyette orchards during 2016. Arrows indicate releases date of *Trichogramma* for both tested doses

32 traps per ha in open- tomato fields in Tunisia. These authors recommended the use of mass trapping through water traps in case of important population of the tomato pinworm that allows capturing of a large number of males of *T. absoluta* without causing saturation problems in the recipient (USDA APHIS 2011).

Infestation

Water and sticky delta traps, were used during all the study period; the latter one seemed to be sufficient in reducing *E. ceratoniae* population and limiting damage of fruits in orchards. In fact, our results showed high reduction of infested pomegranate fruits with 62.3 and 79.8% for water and delta traps, respectively, during harvest. However, no efficacy of any trap type was statistically proved on date palm fruits. Stand-alone mass trapping has been tested for control of a wide range of insect pests such as *C. capitata* (Diptera: Tephritidae) (Andrés and Ferran 2013), *Rhynchophorus ferrugineus* Olivier, 1791 (Coleoptera, Dryophthoridae) (Hamidi et al. 2013), and *T. absoluta* (Lobos et al. 2013). In some programs, mass trapping showed potential for pest management with a significant reduction in target pest population density. Zhang et al. (2002) showed that mass trapping baited with sex pheromone had reduced damages on *Sophora japonica* (L.)

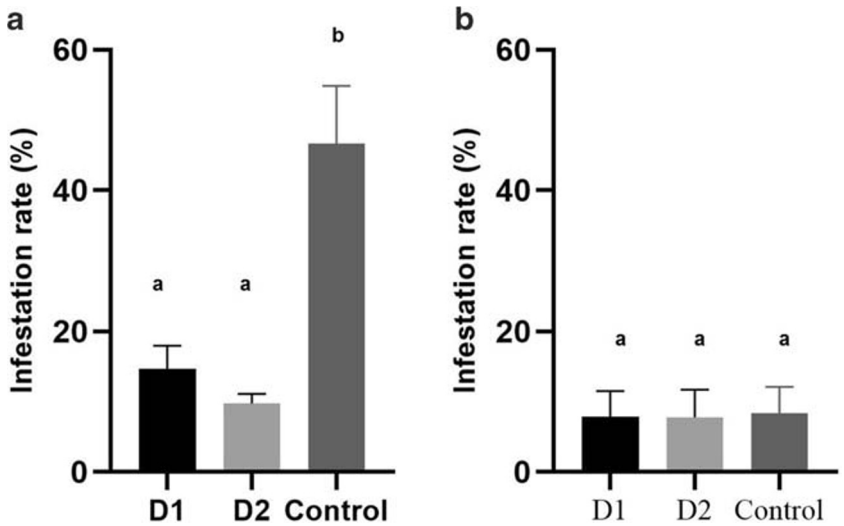

Fig. 12 Infestation of pomegranate (**a**) and date fruits (**b**) after releases of 25,000 (D1) and 50,000 (D2) T/ha compared with control plot in Nefleyette orchards during 2016. Different letters above the bars indicate significant differences ($p \leq 0.05$; Tukey's test)

caused by Chinese tortrix *Cydia trasias* Meyrick, 1928 by 87–96%. Another study conducted with the mass trapping method was conducted on pistachio orchards in Turkey showed that the infestation of *Kermania pistaciella* Amsel, 1964 (Lepidoptera Oinophilidae) in twigs decreased from 50.2 to 5% (Yanik and Yildirim 2016).

In a similar study, Ben Chaabane and Mahjoubi (2019) confirmed that the density of 6 and 15 traps/ha on pomegranate and date palm trees can decrease infestation rate to 4% and 3.2% compared to 20 and 15%, respectively, in control plot during 2018. Another study conducted on pomegranate orchards in northern of Tunisia proved that a density of 10 delta traps per hectare can reduce significantly infestation rate of pomegranate fruits (Dhouibi et al. 2016). Unfortunately, there is no information on how to improve the effectiveness of water traps in catching *E. ceratoniae* in date palm and pomegranate orchards in Tunisia. However, efficiency of mass trapping through water traps was done in monitoring of *T. absoluta* in greenhouses and open field tomato crops (Cherif et al. 2017; Chermiti and Abbes 2012; and Abbes et al. 2012). Thus, our work is the first documented experiment in using water traps as a new alternative to control *E. ceratoniae*. Management of the carob moth population on pomegranate fruit by mass trapping seemed to be satisfying, but no efficiency was recorded on date palm fruits that could be explained by climatic conditions as explained before. In USA, date fruits infested with larvae can cause damage reaching 10–40% to the harvestable date palm orchards each year (Warner et al. 1990; Nay 2005). Bouka et al. (2001) reported 30% yield losses in Morocco for the same host plant. In Tunisia, previous studies showed that this pest causes economic losses in pomegranate fruits exceeding 40% (Braham 2015). It is also a major field pest of pomegranate in Iraq, where the mean percentage of infested fruits increased from 20% to more than 80% (Al-Izzi et al. 1985). Our results demonstrated that mass trapping was not suitable for reducing the density of infested date fruits. However, it was successfully applied in other countries including, among others, Turkey (Demirel 2016) and Iran (Mehrjardy et al. 2016) as the effectiveness on pomegranate fruits was more apparent. Knipling (1979) recommended that for successful mass trapping, more than 95% male annihilation may be required to control high populations of lepidopteran pests.

Trichogramma release

Few studies were conducted to test the impact of parasitoid releases on date palm in Tunisia. However, some studies combined *Trichogramma* releases with other trials. Ben Chaabane and Mahjoubi (2019) tested the efficacy of *Trichogramma* releases combined with mass trapping on date palm and pomegranate trees. Usman et al. (2012) investigated the efficiency of *Trichogramma chilonis* Ishii, 1941 combined with *Chrysoperla carnea* Stephens, 1836 and neem extract against tomato fruit worm *Helicoverpa armigera* Hübner, 1808. Hwang et al. (2010) studied the effect of a combined treatment of *Bacillus thuringiensis* Berliner, 1915 and *Trichogramma ostriniae* Pang & Chen, 1974 to control *Plutella xylostella* Linnaeus, 1758. Also, *Trichogramma pretiosum* Riley, 1879 releases can be combined with pesticides to protect cotton (*Gossypium hirsutum*) (Bastos et al. 2006).

Male captures

Male catches of *E. ceratoniae* were high in all control and treatment plots in 2016. Most of the moths were trapped on 29 August with 16 males/trap in control plot. For both host plants, a significant reduction of male captures was observed between tested doses and control. However, no difference between D1 and D2 in catching carob moth males by delta traps. In a similar study Ben Chaabane and Mahjoubi 2019 mentioned 7 males captures of *E. ceratoniae* per trap after mass trapping and *T. cacoeciae* release in the south-ouest of Tunisia during 2018. Another study was conducted for testing the efficiency of *T. pretiosum* on *Spodoptera frugiperda* J.E. Smith, 1797 male captures which decreased during the trapping period with a total of 60 moths captured in the study period (Figueiredo et al. 2015).

Parasitism rate

Samples taken on 4 July showed very low number of parasitized eggs of carob moth. This is due to the natural parasitism, which proves the existence of parasitoids in date palm orchards of Tozeur with very low densities. Results showed that parasitism rate increased over releases up to 41.4 and 80.2% of parasitized *E. ceratoniae* eggs on pomegranate fruits for D1 and D2, respectively. Mertz et al. (1995) showed that the parasitism rate of *Trichogramma brassicae* Bezdenko, 1968 was between 30% and 50% when tested on *Ostrinia nubilalis* Hübner, 1796 eggs.

Parasitism rates reported for previously tested parasitoid species may be influenced by the number of released parasitoids and spacing among release points (Agamy 1994; Sarhan et al. 2015) given that species of *Trichogramma* are characterised by their reduced capacity of flight, and by the fact that they reach their host eggs by walking and jumping (Chailleux et al. 2013).

Infestation rate

The dose D1 (25,000 T/ha) seems to be suitable to reduce the impact of the carob moth on pomegranate fruits since there was no significant difference recorded for the two tested doses on pomegranate losses. Interestingly, *Trichogramma* egg parasitoids released

would obviously enhance the control performance against many lepidopteran species in Tunisia such as *T. absoluta* and *E. ceratoniae* (Ksentini et al. 2010; Lebdi-Grissa et al. 2010; Abbes et al. 2014). This was successfully applied in other countries including, among others, Egypt (Rizk 2016), USA (Salas et al. 2019), Pakistan (Hussein et al. 2015), and Canada (Dionne et al. 2018). Thus, *Trichogramma* are generally polyphagous parasitoids (Smith 1996). Several studies demonstrated their preference for some host species (Hassan 1989; Attic et al. 2001, Goulart et al. 2011). However, the ability of *Trichogramma* to select and parasitize eggs from the target host is necessary for the success of biological control programs (Pak 1988; Steidle et al. 2001). Zouba (2016) mentioned that females of *T. cacoeciae* and *Trichogramma bourarachae* Pintureau & Babault, 1988 showed a preference for parasitism over *E. ceratoniae* eggs compared to *T. absoluta* eggs with 90% of emergence for both pests. The use of *T. cacoeciae* females has just been targeted for protecting tomato groves (Zouba et al. 2013; Cherif and Grissa-Lebdi 2013; Cherif et al. 2018; Abbes et al. 2014), citrus (Dhouibi et al. 2016) and pomegranate orchards (Lebdi-Grissa and Ben Ayed 2005). About 75% reduction of infestation was achieved by releasing 40 adults of *T. cacoeciae* per plant in greenhouse tomato crops (Zouba and Mahjoubi 2010). In the south of Tunisia, releasing 25,000 of either *T. cacoeciae* or *T. bourarachae,* respectively, induced a reduction of 78% and 87% of damages in protected tomato greenhouses (Zouba et al. 2013). Therefore, the use of *T. caccociae* in pomegranate decreased fruit infestation from 13.2% in untreated plot compared with 2.4% in a treated plot (Lebdi-Grissa and Ben Ayed 2005). Indeed, Khoualdia et al. (1996) showed, through palm grove trials, that the parasitization rate on *E. ceratoniae* eggs averaged 78.7% in the release plots by *T. cacoeciae* and only 45% in date palm orchards of Algeria with *Trichogramma embryophagum* Hartig, 1838 against *E. ceratoniae* (Doumandji-Mitiche 1985; Doumandji-Mitiche and Idder 1986).

Conclusion

The present work showed the effectiveness of some biological methods that can be a promising strategy to control *E. ceratoniae* population in Tunisian oases. A biological control through mass trapping using water and delta traps combined with sex pheromone showed high efficacy in catching *E. ceratoniae* males as well as reducing pomegranate fruits damages during all the study period. However, statistical analyses did not show a significant efficiency on date palm fruit damages comparing with control treatments due to the early harvest during 2016. Therefore, females of *T. cacoeciae* with 25,000 T/ha seem to be a promising alternative limiting the carob moth population.

Overall, *Trichogramma* egg parasitoids released in combination with mass trapping and pheromone-mediated management tactics would obviously enhance the control performance against *E. ceratoniae* in Tunisia. Therefore, it would be interesting to survey neighboring countries, Algeria, Morocco, Libya, for the existence of *E. ceratoniae*. Many experiments should be applied in future to reach the adequate trials including density of mass trapping and *Trichogramma* release for an Integrated Pest Management (IPM) against this pest in Tunisian oases.

Acknowledgments The authors are very grateful to Mourad Lassoued and Mohamed Salah Legtari for their technical assistance. They are also grateful to Ali Zouba for providing crop field. This work was supported by the National Agronomic Institute of Tunisia.

Compliance with ethical standards

Disclosure statement The authors report no conflict of interest.

References

Abbes K, Harbi A, Chermiti B (2012) Comparative study of 2 protection strategies against *Tuta absoluta* (Meyrick) in late open field tomato crops in Tunisia. OEPP/EPPO Bull 42:297–304

Abbes K, Biondi A, Zappala L, Chermiti B (2014) Fortuitous parasitoids of the invasive tomato leafminer *Tuta absoluta* in Tunisia. Phytoparasitica 42:85–92

Abbott WS (1925) A method of computing the effectiveness of an insecticide. J Econ Entomol 18:265–267

Agamy EA (1994) Comparative studies on three species of *Trichogramma* for controlling the European corn borer, *Ostrinia nubilalis* Hübner (Lepidoptera: Crambidae). Cairo University Faculty of Agriculture, PhD Thesis (Printed), Egypt

Ahmadi B, Moharramipour S, Sinclair B (2016) Overwintering biology of the carob moth *Apomyelois ceratoniae* (Lepidoptera: Pyralidae). Int J Pest Manag 62:69–74. https://doi.org/10.1080/09670874.2015.1102984

Aksoy E, Kovanci OB (2016) Mass trapping low-density populations of *Tuta absoluta* with various types of traps in field-grown tomatoes. J Plant Dis Prot 123:51–57. https://doi.org/10.1007/s41348-016-0003-6

Al Barty (2014) Detection of genetic diversity among populations of *Ectomyelois ceratoniae* using RAPD markers. Int J Adv Res 11: 944–951

Al-Izzi MA, Al-Maliky SK, Younis MA, Jabbo NF (1985) Bionomics of *Ectomyelois ceratoniae* (Lepidoptera: Pyralidae) on pomegranates in Iraq. Environ Entomol 14:149–153. https://doi.org/10.1093/ee/14.2.149

Amarasekare KG, Shearer PW, Mills NJ (2015) Testing the selectivity of pesticide effects on natural enemies in laboratory bioassays. Biol Control 102:7–16. https://doi.org/10.1016/j.biocontrol.2015.10.015

Andrés AM, Ferran GM (2013) Mass-trapping of *Ceratitis capitata* (Diptera: Tephritidae) in citrus: how it works and factors to improve

its efficacy. Integ Control Citrus Fruit Crops IOBC-WPRS Bull 95: 43–50

Attic S, Low C, Pintureau B (2001) Effects of the host species and the number of parasitoids per host on the size of some *Trichogramma* species (Hymenoptera: Trichogrammatidae). Biocontrol Sci Techn 11:21–26. https://doi.org/10.1080/09583150020029709

Balachowsky AS (1972) Entomologie appliquée à l'agriculture. Tome II. Lépidoptères, Masson et Cie, Paris, France

Barros EC, Bacci L, Picanco MC, Martins JC, Rosado JF, Silva GA (2014) Physiological selectivity and activity reduction of insecticides by rainfall to predatory wasps of *Tuta absoluta*. J Envir Sci Health 50:45–54. https://doi.org/10.1080/03601234.2015.965621

Basley K, Davenport B, Vogiatzis K, Goulson D (2018) Effects of chronic exposure to thiamethoxam on larvae of the hoverfly *Eristalis tenax* (Diptera, Syrphidae). Peer J 6:e4258. https://doi.org/10.7717/peerj.4258

Bass C, Denholm I, Williamson MS, Nauen R (2015) The global status of insect resistance to neonicotinoid insecticides. Pestic Biochem Physiol 121:78–87. https://doi.org/10.1016/j.pestbp.2015.04.004

Bastos CS, DeAlmeida RP, Asuinaga F (2006) Selectivity of pesticides used on cotton (*Gossypium hirsutum*) to *Trichogramma pretiosum* reared on two laboratory-reared hosts. Pest Manag Sci 62:91–98. https://doi.org/10.1002/ps.1140

Ben Chaabane S, Mahjoubi K (2019) Reduction in carob moth *Ectomyelois ceratoniae* (Lepidoptera, Pyralidae) populations by means of mass trapping pheromone and *Trichogramma cacoecia* (Hymenoptera: Trichogrammatidae) releases in Tunisian oases. J New Sci 61:3866–3873

Bouka H, Chemseddine M, Abbassi M, Brun J (2001) La pyrale des dattes dans la région de Tafilalet au Sud-Est du Maroc. Fruits 56: 189–196. https://doi.org/10.1051/fruits:2001122

Braham M (2015) Insect larvae associated with dropped pomegranate fruits in an organic orchard in Tunisia. J Entomol Nematol 7:5–10

Chailleux A, Biondi A, Han P, Tabone E, Desneux N (2013) Suitability of the pest–plant system *Tuta absoluta* (Lepidoptera: Gelechiidae) tomato for *Trichogramma* (Hymenoptera: Trichogrammatidae) parasitoids and insights for biological control. J Econ Entomol 106: 2310–2321

Charelton RE, Cardé RT (1990) Factors mediating copulatory behavior and close-range mate recognition in the male gypsy moth, *Lymantria dispar* (L.). Rev Canad Zool 68:1995–2004. https://doi.org/10.1139/z90-281

Cherif A, Grissa-Lebdi K (2013) Trichogramma cacoeciae as a biological control agent of the tomato pinworm *Tuta absoluta* in northeastern Tunisia. Entomol Hell 22:35–42

Cherif A, Harbaoui K, Zappalà L, Grissa-Lebdi K (2017) Efficacy of mass trapping and insecticides to control *Tuta absoluta* in Tunisia. J Plant Dis Prot 125:51–61. https://doi.org/10.1007/s41348-017-0140-6

Cherif A, Mansour R, Attia-Barhoumi S, Zappalà L, Grissa-Lebdi K (2018) Effectiveness of different release rates of *Trichogramma cacoeciae* (Hymenoptera: Trichogrammatidae) against *Tuta absoluta* (Lepidoptera: Gelechiidae) in protected and open field tomato crops in Tunisia. Biocontrol Sci Techn 29:149–161. https://doi.org/10.1080/09583157.2018.1542485

Chermiti B, Abbes K (2012) Comparison of pheromone lures used in mass trapping to control the tomato leafminer *Tuta absoluta* (Meyrick, 1917) in industrial tomato crops in Kairouan (Tunisia). Bull OEPP 42:241–248. https://doi.org/10.1111/epp.2561

De Stefani R (1920) Of some insects of the Carrube. Bull R Exp Station Citrus Fruit Grow Acireale 37:5–6

Demirel N (2016) A study on occurrence and population trends of the carob moth, *Ectomyelois ceratoniae* (Zeller) (Lepidoptera: Pyralidae) in pomegranate orchards by using pheromone traps. Entomol Appl Sci Lett 3:26–31

Dermauw W, Pym A, Bass C, Van Leeuwen T, Feyereisen R (2018) Does host plant adaptation lead to pesticide resistance in generalist herbivores? Curr Opin Insect Sci 26:25–33. https://doi.org/10.1016/j.cois.2018.01.001

Desneux N (2010) Biological invasion of European crops by *Tuta absoluta*: ecology, geographic expansion and prospects for biological control. J Pest Sci 83:197–215. https://doi.org/10.1007/s10340-010-0321-6

Dhoubi MH, Jammazi A (1993) Lutte biologique contre la pyrale des caroubes par *Habrobracon hebetor* en verger de grenadier. Med Fac Landbouww Univ Gent 57:427–436

Dhouibi MH, Jemmazi A (1996) Lutte biologique en entrepôt contre la pyrale *Ectomyelois ceratoniae*, ravageur des dattes. Fruits 51:39–46

Dhouibi MH, Hermi H, Soudani D, Thlibi H (2016) Biocontrol of the carob moth *Ectomyelois ceratoniae* in pomegranate and citrus orchards in Tunisia. Int J Agric Innov Res 4:849–856

Dionne A, Khelifi M, Todorova S, Boivin G (2018) Design and testing of a boom sprayer prototype to release *Trichogramma ostriniae* (Hymenoptera : Trichogrammatidae) in sweet corn for biocontrol of *Ostrinia nubilalis* (Hubner) (lepidoptera : crambidae). Am Soc Agri Biol Eng 61:1867–1879. https://doi.org/10.13031/trans.12922

Doumandji-Mitiche B (1985) Les parasites des pyrales des dattes dans quelques oasis Algériennes et particulièrement ceux d'*Ectomyelois ceratoniae* Zeller, (Lepidoptera, Pyralidae). Essai des lachers de *Trichogramma embryophagum* (Hymenoptera, Trichogrammatidae) dans les palmeraies à Ouargla (Algérie). Ann Inst Nat Agr El Harrach 9:14–37

Doumandji-Mitiche B, Idder MA (1986) Essais de lâchers de *Trichogramma embryophagum* Hartig (Hymenoptera, Trichogrammatidae) contre la pyrale des dattes *Ectomyelois ceratoniae* Zeller (Lepidoptera, Pyralidae) dans la palmeraie de Ouargla. Ann ENSA 10:167–180

Echlin TD (1982) Carob moth in California: new state record. California Dep Food Agr Memo, Nov 26

El Sayed AM, Suckling DM, Wearing CH, Byers JA (2006) Potential of mass trapping for long-term pest management and eradication of invasive species. J Econ Entomol 9:1550–1564. https://doi.org/10.1093/jee/99.5.1550

Evreinoff VA (1949) Le grenadier. Fruits d'Outre-Mer 4:161-170

Figueiredo M, Cruz I, Silva R, Edward FJ (2015) Biological control with *Trichogramma pretiosum* increases organic maize productivity by 19.4%. Agr Sustain Dev 35:1175–1183. https://doi.org/10.1007/s13593-015-0312-3

Fornasiero D, Mori N, Triello P, Pozzebon A, Duso C, Tescari E, Bradascio R, Otto S (2017) Effect of spray drift reduction techniques on pests and predatory mites on orchards and vineyards. Crop Prot 98:283–292. https://doi.org/10.1016/j.cropro.2017.04.010

Frank SD (2010) Biological control of arthropod pests using banker plant systems: past, progress and future directions. Biol Control 52:8–16. https://doi.org/10.1016/j.biocontrol.2009.09.011

Gagnon AE, Audette C, Duval B, Boisclair J (2017) Can the use of *Trichogramma ostriniae* (Hymenoptera: Trichogrammatidae) to control *Ostrinia nubilalis* (Lepidoptera: Crambidae) be economically sustainable for processing sweet corn. J Econ Entomol 110:59–66. https://doi.org/10.1093/jee/tow293

García-Martínez O, Pérez-Hedo M, Urbaneja A, Beltrán V, Bartual J, Beitia FJ (2017) Importance of moth species as pests on pomegranate and persimmon crops in the Valencian community (Spain). In IV Int symposium on pomegranate and minor Mediterranean fruits. Elche, Spain

Gothilf S (1984) Biology of *Spectrobates ceratoniae* on almonds in Israel. Phytoparasitica 12:77–87

Goulart MMP, Bueno AF, Oliveira de Freitas Buenos RC, Diniz AF (2011) Host preference of the egg parasitoids *Telenomus remus* and *Trichogramma pretiosum* in laboratory. Rev Bras Entomol 55: 129–133

Graf N, Battes KP, Cimpean M et al (2019) Do agricultural pesticides in streams influence riparian spiders? Sci Total Environ 660:126–135. https://doi.org/10.1016/j.scitotenv.2018.12.370

Grewal SA, Kamboj P, Singh Dua J (2017) Pesticide residues in food grains, vegetables and fruits: a hazard to human health. J Med Chem Toxicol 2:1–7. https://doi.org/10.15436/2575-808X.17.1355

Hached W (2019) Les ravageurs des oranges Thomson, cas d'*Ectomyelois ceratoniae* Zeller (Lepidoptera: Pyralidae): diversité génétique, bio-écologie et moyens de lutte. Institut National Agronomique de Tunisie, Thèse de Doctorat (imprimé), Tunisie

Hached W, Ben Romdhane S, Sahraoui H, Grissa-Lebdi K (2018) Control trials against *Ectomyelois ceratoniae* Zeller 1881 (Lepidoptera: Pyralidae) under controlled conditions and in citrus orchard. J New Sci 49:2961–2970

Hafsi A, Harbi A, Rahmouni R, Chermiti B (2015) Evaluation of the efficiency of mass trapping of *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae) in Tunisian citrus orchards using two types of traps: Ceratrap and Tripack. Int Soc Hortic Sci 1065:1049–1056

Hamidi R, Schmidt-Buesser D, Couzi P, Lherminier B, Khfif K, Renou M, Avand-Faghih A, Rochat D (2013) Piégeage olfactif du charançon rouge du palmier: bases, bonnes pratiques, limites et perspectives. AFPP-3e Conférence sur l'entretien des espaces verts, jardins, gazons, forêts, zones aquatiques et autres zones non agricoles Toulouse Ref 34, pp 261-272

Harbi A, Sabater-Muñoz B, Beitia F, Chermiti B (2018) Biological control of *Ceratitis capitata* (Diptera: Tephritidae) in Tunisia: introduction and potential establishment of *Diachasmimorpha longicaudata* (Hymenoptera: Braconidae) in Tunisian citrus orchards. Integ Control Citrus Fruit Crop IOBC-WPRS Bull 132: 142–149

Hassan SA (1989) Selection of suitable *Trichogramma* strains to control the codling moth *Cydia pomonella* and the two summer fruit tortrix moths *Adoxophyes orana*. *Pandemis heparana* (Lep:Tortricidae). Entomophaga 34:19–27

Hussein D, Ali H, Qasim M, Khan J (2015) Insecticidal susceptibility and effectiveness of *Trichogramma chilonis* as parasitoids of tomato fruit borer, *Helicoverpa armigera*. Pakistan J Zool 47:1427–1432

Hwang IC, Chan P, Dong-Kyun K, Na-Young J, Sun-young J, Mi-Ja S, Jang-Eok K, Young-Nam Y, Yong-Man Y (2010) Combined application of *Trichogramma ostriniae* and *Bacillus thuringiensis* for eco-friendly control of *Plutella xylostella*. J Korean Soc Appl Biol Chem 53:316–322

Jayaraj R, Megha P, Sreedev P (2016) Organochlorine pesticides, their toxic effects on living organisms and their fate in the environment. Inter Discip Toxicol 9:90–100. https://doi.org/10.1515/intox-2016-0012

Khoualdia O, R'houma A, Marro JP (1996) Utilisation de *Trichogramma cacoeciae* Marchal (Hymenoptera, Trichogrammatidae) contre la pyrale des dattes. Ann INRAT 69:197–205

Kim K, Kabir E, Jahan SA (2017) Exposure to pesticides and the associated human health effects. Sci Total Environ 575:525–535. https://doi.org/10.1016/j.scitotenv.2016.09.009

Knipling EF (1979) The basic principles of insect population suppression and management. Agriculture Handbook, Washington USA

Krenn HW (2010) Feeding mechanisms of adult lepidoptera: structure, function, and evolution of the mouthparts. Annu Rev Entomol 55: 307–327. https://doi.org/10.1146/annurev-ento-112408-085338

Ksentini I, Monje JC, JardakT ZN (2010) Naturally occurring egg parasitoids of the genus *Trichogramma* (Hymenoptera: Trichogrammatidae) in a pomegranate orchard in Tunisia. Entomol Sci 13:99–106. https://doi.org/10.1111/j.1479-8298.2009.00356.x

Lebdi-Grissa K, Ben Ayed N (2005) Lutte biologique contre *Ectomyelois ceratoniae* sur grenadier par des lâchers de *Trichogramma cacoeciae*. 7ème Conférence Internationale sur les Ravageurs en Agriculture, Montpellier, p 7

Lebdi-Grissa K, Skander M, Mhafdhi M, Belhadj R (2010) Lutte intégrée contre la mineuse de la tomate, *Tuta absoluta* Meyrick (Lepidoptera : Gelechiidae) en Tunisie. Entomol Faun Entomol 63: 125–132

Levi-Zada A, Sadowsky A, Dobrinin S, Ticuchinski T, David M, Fefer D, Dunkelblum E, Byers JA (2017) Monitoring and mass-trapping methodologies using pheromones: the lesser date moth *Batrachedra amydraula*. Bull Entomol Research 108:58–68

Lobos E, Occhionero M, Werenitzky D, Fernandez J, Gonzalez LM, Rodriguez C, Calvo C, Lopez G, Oehlschlager AC (2013) Optimization of a trap for *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae) and trials to determine the effectiveness of mass trapping. Neotrop Entomol 42:448–457

Madkouri M (1978) Study of the host-parasite relations in the field and laboratory. Awamia 56:37–70

Mahmood I, Imadi SR, Shazadi K, Gul A, Hakeem KR (2016) Effects of pesticides on environment plant, soil and microbes, Springer Int Pub, Cham, pp 253–269. https://doi.org/10.1007/978-3-319-27455-3_13

Mamay M, Levent Ü, Ertan Y, Mahmut D, Ali İ (2016) Efficacy of mating disruption technique against carob moth, *Apomyelois ceratoniae* Zeller (Lepidoptera: Pyralidae) in pomegranate orchards in Southeast Turkey (Şanlıurfa). Int J Pest Manag 62:295–299. https://doi.org/10.1080/09670874.2016.1185552

Mars M, Marrakchi M (1999) Diversity of pomegranate (*Punica granatum* L.) germplasm in Tunisia. Genet Resour Crop Ev 46: 661–467. https://doi.org/10.1023/A:1008774221687

Mediouni J, Dhouibi MH (2007) Mass rearing and field performance of irradiated carob moth *Ectomyelois ceratoniae* in Tunisia. In: Vreysen MJB, Robinson AS, Hendrichs J (eds) Area-wide control of insect pests, Springer, Dordrecht, pp 265-273. https://doi.org/10.1007/978-1-4020-6059-5_25

Mehrjardy AZ, Ravan S, Sahebzadeh S (2016) Effect of larval diet on females' attraction of *Ectomyelois ceratoniae* zeller (lepidoptera: pyralidae) in pheromone traps. Trakia J Sci 14:39–46. https://doi.org/10.15547/tjs.2016.01.005

Mehrnejad MR (1993) Biology of the carob moth *Ectomyelois ceratoniae* a new pest of pistachio in Rafsanjan. Appl Entomol Phytopathol 66: 1–12

Mertz BP, Fleischer SJ, Calvin DD, Ridgway RL (1995) Field assessment of *Trichogramma brassicae* (Hymenoptera: Trichogrammatidae) and *Bacillus thuringiensis* for control of *Ostrinia nubilalis* (Lepidoptera: Pyralidae) in sweet corn. J Econ Entomol 88:1616–1625. https://doi.org/10.1093/jee/88.6.1616

Napoleao TH, Albuquerque LP, Santos N, Nova I, Alima T, Paiva P, Pntual E (2018) Insect midgut structures and molecules as targets of plant derived protease inhibitors and lectins. Pest Manag Sci 75: 1212–1222. https://doi.org/10.1002/ps.5233

Nay JE (2005) Impact of ant predation and heat on carob moth (Lepidoptera: Pyralidae) mortality in California date gardens. J Econ Entomol 98:725–731. https://doi.org/10.1603/0022-0493-98.3.725

Nicolopoulou P, Maipas S, Kotampsi C, Stamatis P, Hens L (2016) Chemical pesticides and human health: the urgent need for a new concept in agriculture. Front Pub Health 4:1–8. https://doi.org/10.3389/fpubh.2016.00148

Norouzi AA, Talebi A, Fathipour Y (2008) Development and demographic parameters of the crob moth *Apomyelois ceratoniae* on four diet regimes. Bull Insectol 61:291–297

Observatoire National de l'Agriculture [ONAGRI] (2018) Analyse des échanges extérieurs des principaux produits agricoles et voies d'amélioration. http://www.onagri.nat.tn/uploads/veille/analyse-echanges-exterieurs.pdf. Accessed Nov 2018

Ouamane AT, Bensalah MK, Djazouli ZE (2017) Approche au monitoring de la pyrale des dattes *Ectomyelois ceratoniae* Zeller par le recours aux moyens biologiques. Agrobiologia 7:312–320

Ozturk N, Lculct M, Ulusoy MR (2011) The adult population dynamics of the carob moth *Ectomyelois ceratoniae* Zell. (Lepidoptera: Pyralidae) in citrus orchards in Adana and Mersin provinces. Bitki Koruma Bulteni 51:347–358

Pak GA (1988) Selection of *Trichogramma* for inundative biological control. PhD. Thesis Agricultural. Wageningen University, PhD Thesis (Printed), Netherlands

Perring TM, El-Shafie HAF, Wakil W (2016) Carob moth, lesser date moth, and raisin moth. Chapter 6. In: Wakil W, Romeno Faleiro J, Miller TA (eds) Sustainable pest management in date palm: Current status and emerging challenges, Springer, Dordrecht, pp 109–167

Rayegan S, Rafie JN, Sadeghi A (2016) The effect of delta trap colors and heights on efficiency of trapping of *Lobesia botrana* (Lepidoptera: Tortricidae) in Iran. J Entomol Zool Stud 4:479–483

Rizk AM (2016) Effectiveness of different bio-techniques for controlling the pin worm, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). Egypt J Biol Pest Cont 4:797–802

Roumani M, Belhamra M, Ben Salah MK (2018) Population dynamics of date moth adults in date palm groves in Sidi Okba Biskra; (Sahara – Algeria). J Fund Appl Sci 10:336–344. https://doi.org/10.4314/jfas.v10i2.24

Salas NG, Aquino D, Vallina C, Biondi A, Luna MG (2019) A re-examination of *Tuta absoluta* parasitoids in South America for optimized biological control. J Pest Sci 92:1343–1357. https://doi.org/10.1007/s10340-018-01078-1

Sarhan AA, Osman MAM, Mandour NS, Abd El-Hady MA (2015) Parasitization capability of four Trichogrammatidae species against the tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) under different releasing regimes. Egypt J Biol Pest Cont 25:107–112

Shakeri M (1993) First report of attack of *Spectrobates ceratoniae* Zell to figs in Iran. Appl Entomol Phytopathol 60:29

Shakeri M (2004) A review on investigations on pomegranate neck worm in Iran. Shakeri M (ed) A proceeding on evaluation of finding and current problems associated with *Spectrobates ceratoniae* management in pomegranate, Organization of Research and Education Ministry of Jihad-e Agriculture Iran, pp 18–30

Sharavari S, Kulkarni LMD, Willenborg CJ (2015) The role of ground beetles (Coleoptera: Carabidae) in weed seed consumption. Rev Weed Sci 63:355–376. https://doi.org/10.1614/WS-D-14-00067.1

Smith SM (1996) Biological control with *Trichogramma*: advances, successes, and potential of their use. Annu Rev Entomol 41:375–406

Sobhani M, Goldansaz SH, Hatami B, Hosseini SA (2015) A field screening of pomegranate cultivars for resistance to the carob moth, *Ectomyelois ceratoniae*, and compatibility with its larval parasitoids. Int J Pest Manag 61:346–352. https://doi.org/10.1080/09670874.2015.1069418

Steidle JLM, Rees D, Wright EJ (2001) Assessment of Australian *Trichogramma* species (Hymenoptera: Trichogrammatidae) as control agents of stored product moths. J Stored Prod Res 37:263–275. https://doi.org/10.1016/S0022-474X(00)00027-8

USDA–APHIS (2011) New pest response guidelines: tomato leafminer (Tuta absoluta). Washington, Department of Agriculture, United States

Usman M, Inayatullah M, Usman A, Sohail K, Shah SF (2012) Effect of egg parasitoid, *Trichogramma chilonis*, in combination with *Chrysoperla carnea* and neem seed extract against tomato fruitworm, *Helicoverpa armigera*. Sarhad J Agric 28:253–257

Vetter RJ, Millar N, Vickers BT (2006) Mating disruption of carob moth, *Ectomyelois ceratoniae*, with a sex pheromone analog. Southwest Entomol 31:33–47

Warner RL, Barnes MM, Laird EF (1990) Chemical control of a carob moth, *Ectomyelois ceratoniae* (Lepidoptera: Pyralidae), and various nitidulid beetles (Coleoptera: Nitidulidae) on 'Deglet Noor' dates in California. J Econ Entomol 83:2357–2361. https://doi.org/10.1093/jee/83.6.2357

Willson HR, Trammel K (1980) Sex pheromone trapping for control of codling moth, oriental fruit moth, lesser appleworm, and three tortricid leafrollers in a New York apple orchard. J Econ Entomol 73:291–295. https://doi.org/10.1093/jee/73.2.291

Yanik E, Yildirim Y (2016) Effectiveness of mass trapping for control of the pistachio twig borer, *Kermania pistaciella*. Bull Insectol 69:35–40

Zhang GF, Meng XZ, Yan H, Sheng CF (2002) Chinese tortrix *Cydia trasias* (Lepidoptera: Olethreutidae): suppression on street-planting trees by mass trapping with sex pheromone traps. Environ Entomol 31:602–607. https://doi.org/10.1603/0046-225X-31.4.602

Zouba A (2016) Caractérisation moléculaire et biologique des espèces de *Trichogramme* (Hymenoptera, Trichogrammatidae) pouvant server comme agent de lutte biologique contre deux ravageurs à importance économique dans les oasis du sud-ouest Tunisien: *Ectomyelois ceratoniae* Zeller (Lepidoptera, Pyralidae) et *Tuta absoluta* Meyrick (Lepidoptera:Gelechiidae). Institut Supérieur Agronomique de Chott Mariem, Thèse de Doctorat (imprimé), Tunisie

Zouba A, Mahjoubi K (2010) Biological control of *Tuta absoluta* (Lepidoptera:Gelechiidae) with release of Trichogramma cacoeciae (Hymenoptera: Trichogrammatidae) in tomato greenhouse in Tunisia. Afr J Plant Sci Biotechnol 4:85–87

Zouba A, Chermiti B, Chraiet R, Mahjoubi K (2013) Effect of two indigenous *Trichogramma* species on the infestation level by tomato miner *Tuta absoluta* in tomato greenhouses in the south-west of Tunisia. Tunis J Plant Prot 8:87–106