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Improving *Ceratitis capitata* control through the mass trapping technique in an IPM programme on apricots in Tunisia

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Abstract: New techniques for *Ceratitis capitata* (Wiedemann, 1824) control are being studied and developed to replace traditional organophosphate pesticide applications. A mass trapping strategy offers promising medfly control within integrated pest management (IPM) programmes. Field assays were performed to study the efficacy of two mass trapping techniques based on PheroNorm® and Ceratrap® lures that were compared to a conventional approach to control the medfly in Tunisian apricot orchards. The results showed that both mass trapping techniques had a similar efficiency in reducing the *C. capitata* population. The degrees Brix in the fruits was a determinant issue since the initial apricot fruit damage was detected at 6.4%. At harvesting, the lowest fruit damage rate was recorded in the PheroNorm® (4.25%) and Ceratrap® (6.50%) treated orchards, compared with the conventional approach (10.75%). Therefore, the use of 50 PheroNorm® and Ceratrap® traps per ha density within an IPM approach may be very useful to control the *C. capitata* populations in apricot orchards.

Keywords: conventional approach; Ceratrap®; degrees Brix; medfly; PheroNorm®; *Prunus armeniaca*

Fruit production plays an important role in the Tunisian economy. Apricots are among the most important exported crops in Tunisia with a total production of around 31 000 tonnes in 2016 (Chebbi et al. 2019). Pests and diseases cause major yield and quality losses. Fruit flies are one of key pests affecting the fruit production. *Ceratitis capitata* (Wiedemann, 1824) (Diptera: Tephritidae) is a serious fruit pest since it is a highly polyphagous, able to damage more than 350 plant species (Liquido et al. 1990). In Tunisia, *C. capitata* cause damage to *Citrus* spp. and to summer fruits, mainly peaches and figs. The presence of *C. capitata* can restrict or close export markets and force farmers to carry out expensive control procedures (Hafsi et al. 2020). The fruit fly in Tunisia is considered as one of the most destructive pests of citrus and peach crops (Bouagga et al. 2014). During these last years, this pest caused very important damage to different varieties of apricots (25%) (unpublished data). This important fruit tree species is cultivated in the in the central part of northern Tunisia, and in the south of Tunisia. *C. capitata* control has a long history in Tunisia, with the first effort documented in 1885, since their first

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documented recording (Fimiani 1989). Up to now, control efforts have been exclusively based on insecticidal bait spray applications. Organophosphates, such as malathion, and pyrethroids mixed with protein bait have been applied in both aerial and terrestrial treatments against *C. capitata* (Howell et al. 1975; Mediouni et al. 2010). Environmental and health problems are commonly associated with organophosphate insecticides (Gerson & Cohen 1989; Michaud 2003; Michaud & Grant 2003; Magaña et al. 2007). The sterile insect technique (SIT) has provided a good effectiveness against *C. capitata* in Costa Rica, Italy, Mexico and Peru. SIT was applied during 2007 in the Bani Khalled area (Tunisia) as an alternative to pesticides, but the results were not encouraging (Mediouni et al. 2010; Hafsi et al. 2015). This technique is preferably employed on a medium to low density *C. capitata* population or in an isolated area to avoid re-infestation (Jacas et al. 2010). Several studies have shown that to be effective, the SIT must be applied in combination with other control methods as part of an integrated pest management strategy (Barry et al. 2003; Alfaro et al. 2010). For these reasons, this control method was applied for two years without bringing any satisfying results, which led to its abandonment (Cheikh et al. 1975). However, the use of mutant strains in Tunisia showed good field performance and induced a wild medfly population decrease three- to five-fold compared with the control which improved the effectiveness of the SIT (Cayol & Zarai 2001). In recent years, the mass trapping technique has received much attention with regards to *C. capitata* management and different traps have been developed and employed in many countries including Greece, Spain (Navarro-Llopis et al. 2008; Martinez-Ferrer et al. 2012) and Tunisia (Kheder et al. 2015; Tlemsani & Kheder 2015). Mass trapping reduces the *C. capitata* population levels and rate of damaged fruit in Tunisian citrus orchards when it is applied at 80 traps per ha (Hafsi et al. 2015). The efficacy of mass trapping is mainly related to the degree of isolation or the size of the protected orchard and to the density of the pest population (El-Sayed et al. 2006). The best control of the *C. capitata* population is obtained in isolated orchards (Broumas et al. 2002). In addition, mass trapping is selective toward non target insects, including useful auxiliary fauna (Hafsi et al. 2015). Thus, this technique has been used in integrated pest management (IPM) programmes in order to achieve sustainable agricultural production with less damage to the environment (Vargas et al. 2015). While IPM has many definitions, it often includes a diverse mix of approaches to manage pests and keep them below economically damaging levels, using field sanitation, the application of protein bait sprays, cultural controls (Vargas et al. 2008). In recent years, IPM has been seen as an effective method for managing fruit flies like *Bactrocera dorsalis* (Hendel, 1912) and *Bactrocera cucurbitae* (Coquillett, 1899) in Hawaii (Vargas et al. 2008) and *B. dorsalis* in India (Verghese et al. 2004, 2006).

C. capitata prefers to lay eggs in ripening fruits (Katsoyannos et al. 1998; Papadopoulos et al. 2001), and the larvae develop inside fruits only when they are mature (Fletcher 1989). To determine the receptive phonological stage at which a fruit can be receptive to *C. capitata* females will allow one to choose the proper time of application of treatments. For instance, Martinez-Ferrer et al. (2012) reported the first damage in citrus when fruits reach an average colour index of 10.

The objective of this study was to assess the effectiveness of two different lures (PheroNorm®, Ceratrap®) used in mass trapping methods (within the framework of an IPM approach against *C. capitata* in Tunisian apricot orchards. The IPM approach included mass trapping using two different lures (PheroNorm®, Ceratrap®), a chemical treatment that was applied only around plots, and sanitation. In addition, the effectiveness of the IPM approach was compared to the conventional approach using protein bait spray treatments.

MATERIAL AND METHODS

Description of the treatments

Traps and lures. The mass trapping techniques were tested using McPhail traps baited with Ceratrap® or PheroNorm® lures. Ceratrap® (Bioibérica S.A.U., Spain) is a liquid protein-based lure derived from enzymatic hydrolysis and the PheroNorm® (Andematt Biocontrol, Switzerland) lure is a synthetic solution based in amines that acts as a feed attractant of fruit flies, especially for females of *C. capitata*. McPhail traps baited with both lures were deployed in apricot trees at a density of 40 traps/ha on April 10, 2015 and were maintained in the field for three months. The quantity of the Ceratrap® and PheroNorm® lures in the McPhail traps were checked monthly in order to note when the quantity decreased to half this quantity was decreased to half the original volume.

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Protein bait spray. It is a foliar cover spray applied using an insecticide mixed with a Lysatex SC protein bait (concentration 350g/L) (SEPCM, Tunisia). The insecticides used, in our case, were dimethoate (April 20, 2015) and thiacloprid + deltamethrin (May 8 and 22, 2015 and June 10, 2015). The protein bait spray was applied with a high-pressure sprayer equipped with turbulence chamber nozzles at a pressure of 6–7 bars. It was applied according to regular agricultural practices and the manufacturer's guidelines, thus ensuring the complete and even coverage of the tree canopies (Hafsi et al. 2016). The details of the chemical treatments in the experimental plots during the whole trial can be found in Table 1.

Sanitation. Sanitation is a cultural control, including pre-harvest methods, applied when damaged fruit are found on the trees or on the ground; they are collected weekly in plastic bags and put into garbage containers, to be buried some km distance from the research area.

Field experiments

The experiment was carried out in 2015 in three blocks of commercial apricot groves located in the region of Utique in northern Tunisia and having the same varieties of apricot. Blocks of 2.1 ha each were divided into three 0.7 ha plots, corresponding to the three control formulations (IPM with PheroNorm® traps, IPM with Ceratrap® traps, and the conventional approach) (Figure 1). In all the plots, the growers controlled the *C. capitata* population for three months starting in middle March, 2015. The plots treated with the IPM approach received the protein bait spray, sanitation, and mass trapping using the PheroNorm® or Ceratrap® food attractant. The plots treated with the conventional approach received the bait sprays treatments and sanitation. The treatments are summarised in Table 1.

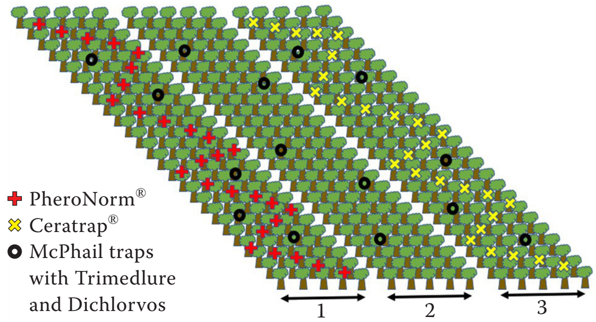

Figure 1. Set-up of the experimental procedure
1 – integrated pest management (IPM) + PheroNorm®; 2 – conventional approach; 3 – IPM + Ceratrap®

The air temperature was monitored in the experimental area using WatchDog® (Spectrum Technologies, USA) data loggers.

Assessment of the *C. capitata* males population

To monitor the *C. capitata* male population, five McPhail traps with Trimedlure and Dichlorvos on each plot were located from April 3 to June 5, 2015 and were checked weekly. All the captured adults

Table 1. Background information on the growth and control modalities tested in this study

Control modalities	Treatments	Date	Treatment locality
IPM + Ceratrap®	dimethoate	20. 4. 2015	surrounding of grove
	thiacloprid + deltamethrin	8. 5. 2015	surrounding of grove
		22. 5. 2015	apricot grove
		10. 6. 2015	apricot grove
	Ceratrap® traps	10. 4. 2015	apricot grove
IPM + PheroNorm®	dimethoate	20. 4. 2015	surrounding of grove
	thiacloprid + deltamethrin	8. 5. 2015	surrounding of grove
		22. 5. 2015	apricot grove
		10. 6. 2015	apricot grove
	PheroNorm® traps	10. 4. 2015	apricot grove
Conventional	dimethoate	20. 4. 2015	surrounding of grove
	thiacloprid + deltamethrin	8. 5. 2015	surrounding of grove
		22. 5. 2015	apricot grove
		10. 6. 2015	apricot grove

IPM – integrated pest management

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of *C. capitata* were counted. After each sampling, the adults were removed from the traps (Figure 1).

Evaluation of fruit damage

Evaluation of the fruit damage caused by females of *C. capitata* were carried out six weeks before harvesting. In each plot, 10 representative trees were selected and marked. From each tree, 20 fruits from each side (east, west, north and south) were chosen and numbered. The accumulated number of damaged fruits was recorded weekly.

Evaluation of apricot Brix index

In order to determine the relationship between the degree of maturity of the fruits and the rate of fruit damage, the Brix index of the fruits was measured using a universal hand refractometer (Refracto 30GS, Mettler, France). The Brix index was measured for a single fruit and was repeated for a total of 60 randomly selected fruits per plot. The Brix index was measured weekly from April 26 to June 5, 2015.

Statistical analyses

All the statistical analyses in this study were performed using R Core project for statistical computing (version 2008).

The amount of the male population of *C. capitata* in the traps was analysed using a generalised linear model (GLM) with a Poisson error (Log link) of the treatment, date and interaction between these two factors. A GLM with binomial error (logit link) was used to analyse the proportion of the fruit damaged as a function of the treatment and date. The data recorded from measuring the degrees Brix in the apricot fruit were analysed as a function of the date by GLM with a quasi-binomial error (logit link).

RESULTS

Assessment of *C. capitata* male population

The captured medfly adults differed significantly between the dates ($Dev_{8,43}$ = 53.11, P < 0.001) and between the treatments in all the dates ($Dev_{2,54}$ = 92.60, P < 0.001). The captured number of male medflies started below 0.22 males/trap per day until May 1, 2015 throughout the study. Later, the number of males captured increased rapidly and peaked two times during the season for all the treatments on May 8, 2015 and May 22, 2015 with 0.50 and 0.28 males per trap/day, respectively, in the conventional approach (Figure 2). The total number of medfly adults captured on all the dates was higher in the conventional approach (55 males) than with the IPM using the mass trapping methods, and it was higher in the PheroNorm® (41 males) than in the Ceratrap® (22 males) treated plots.

Fruit damage assessment

The Brix index increased significantly as a function of the date (R^2 = 0.84; P = 0.003). The mean Brix value of 8.30% (May 21, 2015) indicates that the colour of the apricot fruits shifted from green to yellow and 12.3% (June 5, 2015) indicates the harvest time for the apricot fruits (Figure 3).

No fruit damage by larva feeding was detected before May 14, 2015. Since this date, the fruit damage rate differed significantly among the treatments ($F_{2,201}$ = 371.06; P < 0.001) and increased significantly as a function of the date ($F_{6,203}$ = 393.16; P < 0.001) reaching its maximum at harvesting (Figure 4). The interaction between these factors was non-significant ($F_{12,189}$ = 353.31; P = 0.12). At the time of harvesting, the fruit damage rate was higher in the conventional approach (10.75%) than in the IPM approach with the Ceratrap® (6.30%) and PheroNorm® (4.25%) mass trapping.

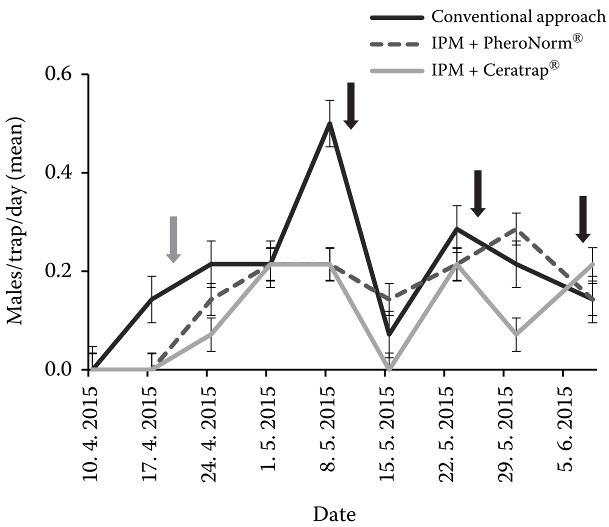

Figure 2. Mean of the captured number of *Ceratitis capitata* males per trap and the day in the three control modalities: Conventional approach, integrated pest management (IPM) + PheroNorm® and IPM + Ceratrap®
The arrows indicate when the insecticides bait sprays were applied (light grey for dimethoate, dark grey for thiacloprid + deltamethrin)

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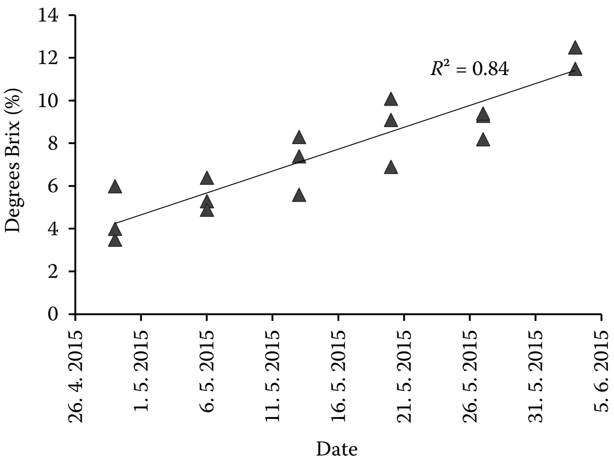

Figure 3. Degree Brix (%) in the apricot fruits as a function of the date of measurement using a universal hand refractometer

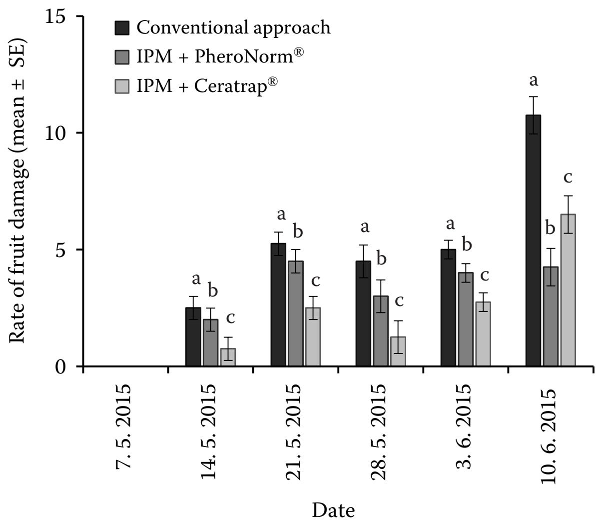

Figure 4. Mean and SE of the apricot fruit damaged by *Ceratitis capitata* in plots treated with the conventional approach, integrated pest management (IPM) + PheroNorm® and IPM + Ceratrap® in the Utique area

The data followed by different letters are significantly different

DISCUSSION

The results obtained in this study showed that the mass trapping technique used in the IPM approach was an effective pest management method. The mass trapping technique has proven to be as effective as insecticide sprays to control *C. capitata* in citrus orchards in Mediterranean countries (Leza et al. 2008) including Tunisia (Hafsi et al. 2016). This study confirms that the mass trapping technique is effective to reduce the population levels and fruit damage rate. However, the two food attractants (PheroNorm® and Ceratrap®) used in the mass trapping technique gave highly varying efficacies in the *C. capitata* catches and the rate of fruit damage.

C. capitata adults were not found in the apricot orchards before April 10, 2015 which can be related to the weather conditions in the Utique area and especially to the temperatures, below 15 °C (Figure 5). Duyck and Quilici (2002) showed that high levels of survivorship of all stages of *C. capitata* were observed over the range 15–30 °C with a maximum at 25 °C which is consistent with previous studies (Messenger & Flitters 1958; Crovetti et al. 1986; Vargas et al. 1996). From the 17th of April 2015, the *C. capitata* population was very similar in all the treated plots showing an important increase in the trap captures that may be attributed to the favourable weather conditions during this period. In contrast, the *C. capitata* males captured in the three groves fell drastically immediately after the bait spray applications on May 8, 2015 in all the groves. One week later, the *C. capitata* males increased in all the groves, then showing a low persistency of the bait spray with thiacloprid and deltamethrin.

The Brix index and colours (Katsoyannos et al. 1998; Papadopoulos et al. 2001) are indicators of the fruit ripening and, therefore, of the phenological stage of the fruit punctured by *C. capitata* females that prefer to lay eggs in ripening or ripe fruits. In this study, the first fruit attacked by the *C. capitata* females was found when the Brix index of the apricot fruits reached 10% in the second and third weeks of May 2015 throughout the study. The fruit Brix index is a determinant issue in the

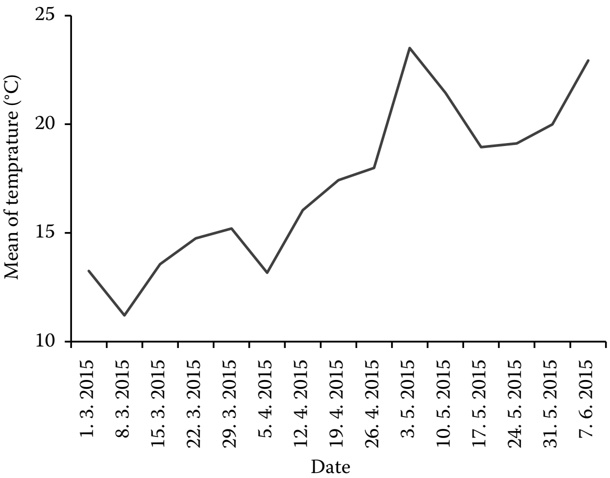

Figure 5. Mean temperatures between March and June recorded in the apricot groves in the Utique area (2015)

rate of fruit damage as if a certain maturity degree is not achieved, the fruits are not susceptible to being attacked by *C. capitata* females. However, other factors can be involved in the attack of *C. capitata* to the fruits, such as the population level of the flies in orchards, which is determined by the temperature (Martinez-Ferrer et al. 2010). The population levels in the monitoring traps and ripening status of the fruit hosts in the orchards are the main factors used to make pest management decisions against *C. capitata*. In the case of a lack of information about the phenological stage in which the fruit can be receptive to *C. capitata* female, it would lead one to underestimate the proper time of the treatment application(s).

The lowest rate of fruit damage (6.50%) was observed in the plots treated with the IPM approach, showing the efficacy of this technique against *C. capitata* in apricot orchards compared to the conventional approach. Similar results were observed in previous studies showing the efficacy of Ceratrap® in reducing the rate of fruit damage compared to chemical treatments in Tunisian citrus orchards under different farming systems (Hafsi et al. 2015). PheroNorm®, a new type of synthetic food attractant, was tested for the first time against *C. capitata* in this study showing the best performances in the catching capacities and protection of the fruit until harvesting. The rate of fruit damage at harvesting in the groves treated with the PheroNorm® mass trapping was 4.25% and can be considered low compared with groves treated with insecticide bait sprays, and growers can accept it. Taking into account that no chemical treatments were applied on the apricot trees and major chemical treatments were often applied only to the perimeter row, and according to the results obtained, we suggest that mass trapping with the PheroNorm® food attractant can be a valid standalone control and can be included in the IPM approach against *C. capitata*.

For mass trapping, besides the cheaper and more efficient trap and attractant used, the density of traps per ha and the population level will be crucial in determining the efficacy of this technique as a pest control measure (El-Sayed et al. 2006). Because of the high cost of the traps, the density of 50 traps per ha has been suggested as being appropriate against *C. capitata* in citrus orchards in Spain (Blas et al. 2005; Navarro-Llopis et al. 2008). Even 25 traps per ha density appears to be a valid stand-alone method to protect mid-season varieties of citrus in Spain (Martinez-Ferrer et al. 2010). In our study, we suggest that the density of 40 traps per ha used in this study for IPM strategy in seasonal apricots could be enough to provide the successful control of *C. capitata* in isolated apricot orchards in Tunisia.

The mass trapping technique has been tested in many Mediterranean countries and was found to be a very effective pest management tool against *C. capitata* (Navarro-Llopis et al. 2008; Hafsi et al. 2016), but the high costs of the traps and food attractants are considered as limiting factors (Navarro-Llopis et al. 2013). The results obtained in this study found that the fruit damage rate was two times lower in the IPM method with the mass trapping than in the conventional approach. Despite this small reduction in the fruit damage, the cost of the mass trapping technique would not be an obstacle for the implementation and success of this technique, and an IPM strategy with mass trapping could be applied because it has a positive ecological profile (Hafsi et al. 2016).

CONCLUSION

Field trials showed that the IPM approach including the mass trapping technique provided an acceptable control of *C. capitata* in commercial apricot orchards compared to the conventional approach. The two food attractants tested in this study gave highly varying efficacies in the *C. capitata* catches and the rate of fruit damage. The PheroNorm® attractant trap had the highest efficiency because the best traps ensure the lowest rate of fruit damage than traps giving worse results. The IPM approach included PheroNorm® mass trapping and was combined with sanitation and pesticide treatments to the perimeter row of the grove can offer the successful control of *C. capitata* in apricot orchards.

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