JOURNAL OF APPLIED ENTOMOLOGY

J. Appl. Entomol.

ORIGINAL CONTRIBUTION

Attract-and-kill systems efficiency against *Ceratitis capitata* (Diptera: Tephritidae) and effects on non-target insects in peach orchards

A. Hafsi[1,2], K. Abbes[1], A. Harbi[1,3], P.-F. Duyck[2] & B. Chermiti[1]

1 Institut Supérieur Agronomique de Chott-Mariem, Laboratoire d'Entomologie et de Lutte Biologique, Université de Sousse, Sousse, Tunisie

2 CIRAD, UMR PVBMT, CIRAD/Université de La Réunion, Pôle de Protection des Plantes, Saint-Pierre, La Réunion, France

3 Instituto Valenciano de Investigaciones Agrarias (IVIA), Centro de Protección Vegetal y Biotecnología, Unidad Asociada de Entomología UJI-IVIA, Moncada, Spain

Keywords

AAL&K, Ceranock, conventional approach, IPM, medfly

Correspondence

Brahim Chermiti (corresponding author), Institut Supérieur Agronomique de Chott-Mariem, Laboratoire d'Entomologie et de Lutte Biologique, Université de Sousse, 4042 Sousse, Tunisie. E-mail: chermiti54@yahoo.fr

Received: April 7, 2015; accepted: July 13, 2015.

doi: 10.1111/jen.12259

Abstract

For control of the Mediterranean fruit fly *Ceratitis capitata* (Diptera: Tephritidae), the attract-and-kill or attracticide technique is an alternative to the spraying of traditional organophosphate pesticides. In this study, the effectiveness of Ceranock and AAL&K attract-and-kill bait stations was assessed for control of *C. capitata* in Tunisian peach (*Prunus persica*) orchards. Our results showed that, in orchards with early-ripening varieties, the numbers of *C. capitata* males and fruit damage were significantly lower in plots treated with Ceranock and AAL&K bait stations than in plots treated with conventional organophosphate and pyrethroid insecticides. In addition, the abundances of non-target insects in the Chrysopidae, Coccinellidae and Miridae were significantly greater in plots treated with the bait stations than in plots treated with the conventional pesticides; that is, the use of attract-and-kill bait stations had fewer negative effects than the application of conventional pesticides on the biological diversity in Tunisian peach orchards. Overall, the results indicate that Ceranock and AAL&K attract-and-kill bait stations are useful alternatives for the control of *C. capitata* in Tunisian peach orchards planted with early-ripening varieties.

Introduction

The Mediterranean fruit fly or medfly, *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae), is a highly polyphagous and multivoltine pest worldwide (Liquido et al. 1990). In Tunisia, *C. capitata* is one of the most economically important pests of citrus, peach, fig and apricot; the direct damage to fruits caused by *C. capitata* results in yield losses equivalent to 4.5 million U.S.$ (Driouchi 1990). Control of *C. capitata* has mainly relied on the application of organophosphate insecticides and especially malathion mixed with protein baits (Boulahia-Kheder et al. 2012). There are several problems with the use of these insecticides. For example, resistance to malathion was found in *C. capitata* populations in Spain (Magana et al. 2007). Also, malathion-based insecticides have negative effects on non-target insects (Michaud 2003; Michaud and Grant 2003) and can result in secondary outbreaks of other pests (Gerson and Cohen 1989). Moreover, the use of insecticides against *C. capitata* does not always prevent fruit damage. Alternatives to these organophosphate insecticides are clearly needed.

As an alternative to these insecticides, the attract-and-kill technique of mass trapping is used in many countries including Spain and Greece (Navarro-Llopis et al. 2008). Although mass trapping reduced *C. capitata* adult numbers and fruit damage in Tunisian orchards (Hafsi et al. 2015), the high costs of traps and attractants are considered limiting factors (Navarro-Llopis et al. 2013).

Other forms of attract-and-kill techniques need to be tested for the control of *C. capitata*, and one such technique is referred to as the bait station system. Bait station systems differ from mass trapping systems in that bait stations do not retain target insects in traps (El-Sayed et al. 2009; Navarro-Llopis et al. 2014). Various bait station systems have been developed and appear to be less expensive than current mass trapping systems (Navarro-Llopis et al. 2013) and effective at reducing fruit loss by maintaining adult *C. capitata* numbers under the economic threshold. Several studies proved the efficiency of this technique under low and high pest densities against pests in the Lepidoptera (Mansour 2009; Kroschel and Zegarra 2013) and Tephritidae (Martinez-Ferrer et al. 2010). Control with bait stations relies on a comprehensive understanding of the orientation behaviour and movement of adult flies with respect to oviposition and food resources (Miranda et al. 2001) and also relies on an understanding of insecticide efficacy (Manrakhan et al. 2013). The current study evaluates the use of two commercial bait station systems: the Ceranock and the AAL&K bait stations. Although the Ceranock attract-and-kill bait station system has been found to control *C. capitata* in Tunisian peach orchards (Bouagga et al. 2014), there are concerns regarding the effects of food-based attractants on the environment and on the non-target organisms (Burns et al. 2001; Barry et al. 2003). AAL&K bait stations have not been studied in Tunisia.

The first objective of our study was to compare the effects of Ceranock and AAL&K attract-and-kill bait stations with the spray application of deltamethrin and dimethoate insecticides on *C. capitata* numbers and fruit damage in early and mid-season variety. The second objective was to evaluate the effects of these treatments on the abundance of non-target insects.

Materials and Methods

Attract-and-kill systems

Two types of attract-and-kill bait stations were tested. The Ceranock® bait station, which was supplied by Russell IPM (United Kingdom), has three parts: a plastic hook, which is used to hang the device from a tree branch; a plastic case; and a sponge impregnated with the attractive bait (hydrolysed proteins and citrus plant extract at 5 g/bait station) and insecticide (alpha-cypermethrin at 0.01 g/bait station). The average 'lifespan' of this bait station is 4 months under normal field conditions. As recommended by the manufacturer, 400 Ceranock bait stations/ha were deployed in the peach orchards in this study.

The AAL&K® bait station, which was supplied by Atlas Agro (Switzerland), consists of a tube containing 150 g of attracticide paste, which is a mixture of attractive bait (enriched ginger oil as male *C. capitata* parapheromone at 10%), insecticide (permethrin at 6%) and stabilizer (at 84%). This product is applied as droplets of paste on the trees, and its average lifespan is 4 weeks under normal field conditions. As recommended by the manufacturer, it was applied in peach orchards with an average of 3000 droplets (225 g)/ha (6–7 droplets per tree), and droplets were placed on the undersides of leaves.

Field experiments

Experiments were conducted in three peach orchards in Tunisia. In two orchards, which were planted with early varieties (one with San-Pedro and the other with Flordastar), experiments were conducted from March to June 2013; these orchards were located in the Alelcha and Ourdanine areas in the coastal region of Tunisia (table 1). In one orchard, which was planted with a mid-season variety (Royal Glory), an experiment was conducted from May to July 2014; this orchard was located in north-eastern Tunisia (table 1). In each orchard, the efficacy of Ceranock and AAL&K bait stations was compared with a conventional approach that used an organophosphate insecticide (dimethoate at 100 ml/hl) and a pyrethroid insecticide (deltamethrin at 83 ml/hl) as cover sprays. Each of the three orchards had three plots of 1 ha each corresponding to the three treatments (the conventional insecticides and the Ceranock and AAL&K bait stations). The treatments are summarized in table 1. In plots treated with conventional insecticides, the insecticides were applied according to regular agricultural practices and label guidelines. The insecticides were applied with a high pressure sprayer equipped with turbulence chamber nozzles. Insecticides were sprayed at a pressure of 6–7 bars to run-off resulting in complete and even coverage of the tree canopies. The bait stations were deployed at the rates indicated in the previous section and on the dates indicated in table 1.

Monitoring of *C. capitata* numbers

To monitor the numbers of male *C. capitata* in all plots, we used 'McPhail' traps baited with trimedlure mixed with dichlorvos (DDVP) as a killing agent. Six of these traps were placed in each plot and were checked

Table 1 Background information on the orchards and treatments used in this study

Orchard (area)	Coordinates	Treatment	Active ingredient (AI)	Application number	Application date
Alelcha	35°42′29″N 10°40′35″E, elevation: 58 m	Conventional approach	Dimethoate	2	13 March 2013 24 March 2013
			Deltamethrin	1	24 April 2013
		Ceranock attract-and-kill	α-Cypermethrin	1	30 March 2013
		AAL&K attract-and-kill	Permethrin	2	30 March 2013 02 May 2013
Ouardanine	35°31′46″N 10°33′06″E, elevation: 96 m	Conventional approach	Dimethoate	2	24 April 2013 25 May 2013
			Deltamethrin	1	15 May 2013
		Ceranock attract-and-kill	α-Cypermethrin	1	30 March 2013
		AAL&K attract-and-kill	Permethrin	2	30 March 2013 02 May 2013
Morneg	36°40′52″N 10°17′26″E, elevation: 32 m	Conventional approach	Dimethoate	3	07 May 2014 22 May 2014 19 June 2014
			Deltamethrin	3	19 March 2014 03 April 2014 22 April 2014
		Ceranock attract-and-kill	α-Cypermethrin	1	07 May 2014
		AAL&K attract-and-kill	Permethrin	3	07 May 2014 28 May 2014 18 June 2014

weekly. The males of *C. capitata* captured in each trap were counted and removed weekly.

Evaluation of fruit damage

In each plot, 10 trees were randomly selected and marked. From each one, 20 fruits from each orientation (east, west, north and south) were marked and examined. The number of oviposition punctures per marked fruit was determined weekly. For each tree, the proportion of fruit damaged was calculated as the number of fruit with at least one oviposition puncture over the total number of examined fruits.

Effect of Ceranock and AAL&K bait stations on non-target insects

The effects of the two kinds of attract-and-kill bait stations on the abundance of non-target insects were assessed in the orchards at Alelcha and Ouardanine using beat sheet samples. Samples were collected 7 days before and 5, 12 and 19 days after the bait stations were deployed or after deltamethrin and dimethoate were applied. Each sampling was carried out on 15 trees per plot according to the method described by Fauvel et al. (1981). On each sampling date, five branches per tree were beaten, and insects were collected on a white rectangular beat sheet, giving a total of 75 sampled branches per treatment per sampling date per plot. The samples were kept in 90% alcohol and were identified to family and counted in the laboratory. The families of non-target insects selected for this study were Chrysopidae (Neuroptera), Coccinellidae (Coleoptera) and Miridae (Hemiptera). These families were selected because they contain species that are common and important in peach orchards in Tunisia.

Statistical analysis

For each orchard, a generalized linear model (GLM) with Poisson error (Log link) was used to determine how numbers of *C. capitata* males caught in the McPhail traps were affected by treatment (Ceranock bait station, AAL&K bait station or conventional approach), date and the interaction between treatment and date. We then compared the curves describing changes in male numbers over time for the three treatments by calculating area under disease progress curve (AUDPC) values, which were then analysed using analysis of variance (ANOVA).

A GLM with binomial error (logit link) was used to analyse the proportions of fruit damaged as a function of treatment, date and interaction between these two factors.

A GLM with Poisson error (Log link) was used to analyse the abundances of non-target insects as a function of treatment, date and their interaction. All statistical analyses were performed using R project for statistical computing (R Development Core Team, 2008).

Results

C. capitata numbers

As indicated by AUDPC values, the abundance of *C. capitata* males significantly differed among treatments in the Alelcha orchard ($F_{2,\ 15} = 129.81$, $P < 0.001$), in the Ouardanine orchard ($F_{2,\ 15} = 43.18$, $P < 0.001$) and in the Morneg orchard ($F_{2,12} = 357.6$, $P < 0.001$).

In the Alelcha orchard, the abundance of *C. capitata* males was affected by treatment ($Dev_{2,\ 243} = 818.6$, $P < 0.001$), date ($Dev_{14,\ 229} = 6868.3$, $P < 0.001$) and their interaction ($Dev_{24,\ 205} = 50.2$, $P = 0.0013$). *C. capitata* males were significantly more abundant in plots treated with conventional insecticides than in plots treated with AAL&K and Ceranock bait stations (fig. 1a).

In the Ouardanine orchard, the abundance of *C. capitata* males was affected by treatment ($Dev_{2,\ 243} = 8477.1$, $P < 0.001$), date ($Dev_{14,\ 229} = 7763.2$, $P < 0.001$) and their interaction ($Dev_{24,\ 205} = 55.8$, $P < 0.001$). The number of males was initially low and did not exceed 1.9 individuals/trap/day until 27 April 2013 (fig. 1b). After this date, *C. capitata* numbers increased steadily to a peak on 8 June 2013.

In the Morneg orchard, the abundance of *C. capitata* males was affected by treatment ($Dev_{2,\ 133} = 2571.1$, $P < 0.001$) and date ($Dev_{8,\ 299} = 7077.00$, $P < 0.001$) but was not affected by their interaction ($Dev_{16,\ 109} = 55.80$, $P = 0.40$). Numbers of *C. capitata* males did not differ among treatments until 13 May 2014 (fig. 1c). After this date, *C. capitata* numbers increased more in plots treated with Ceranock and AAL&K bait stations than in plots treated with conventional insecticides.

The numbers of *C. capitata* males differed among the three orchards ($P < 0.001$). The numbers were lower in orchards with the early-ripening varieties (in Alelcha and Ouardanine) than in the orchard with the mid-season ripening peach variety (in Morneg).

Fruit damage

The proportion of fruit damaged was affected by treatment and date in the Alelcha orchard ($Dev_{2,\ 537} = 439.44$, $P < 0.001$; $Dev_{14,\ 529} = 2601.49$, $P < 0.001$, respectively), in the Ouardanine orchard ($Dev_{2,\ 537} = 779.00$, $P < 0.001$; $Dev_{14,\ 529} = 2601.49$, $P < 0.001$, respectively) and in the Morneg orchard ($Dev_{2,\ 207} = 1275.50$, $P < 0.001$; $Dev_{8,\ 201} = 3777.40$, $P < 0.001$, respectively). The interaction between treatment and date was significant in the Morneg orchard ($Dev_{16,\ 189} = 15.60$, $P < 0.001$) but not in the other two orchards.

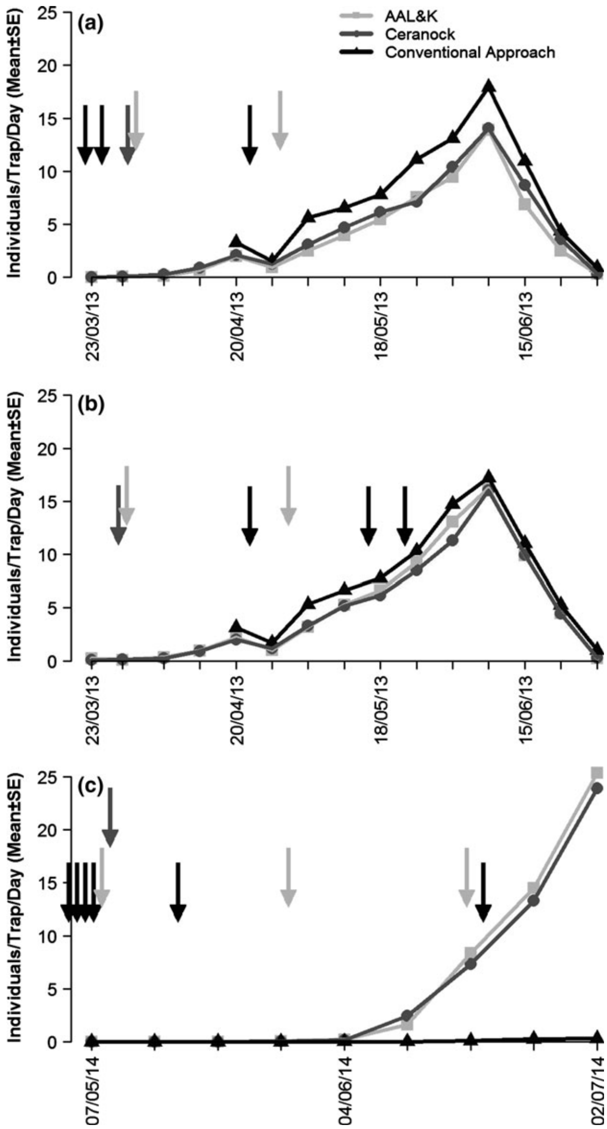

Fig. 1 Mean numbers of *C. capitata* males captured per McPhail tarp and per day in plots treated with AAL&K and Ceranock attract-and-kill bait stations and with conventional insecticides in three peach orchards in Tunisia. (a) the Alelcha orchard in 2013; (b) the Ouardanine orchard in 2013; and (c) the Morneg orchard in 2014. Arrows indicate when bait stations were deployed (light grey for AAL&K, dark grey for Ceranock) and when insecticides were applied (black).

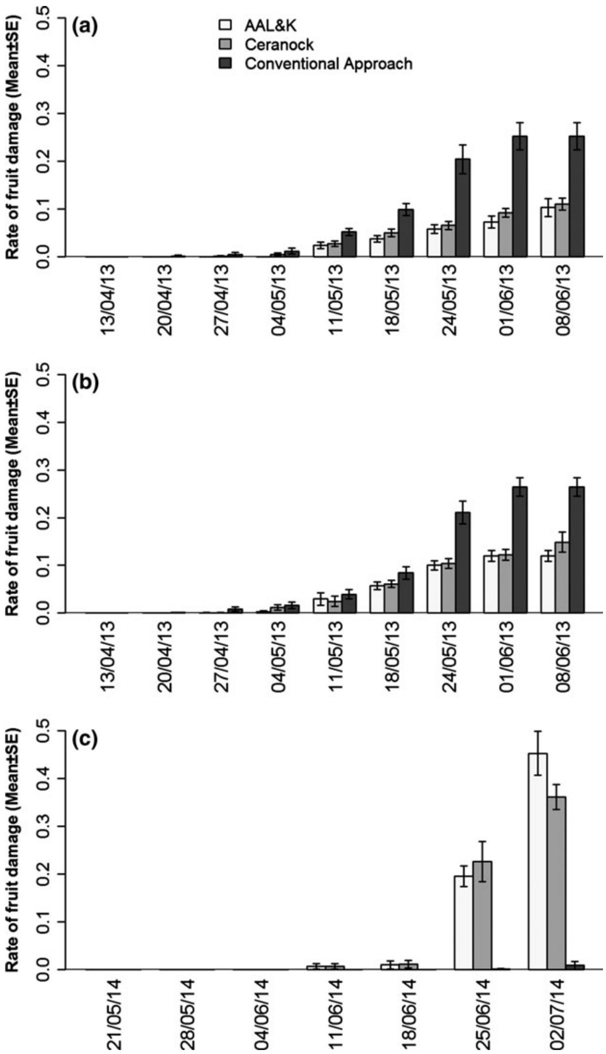

Fig. 2 Proportion of fruit damaged by *C. capitata* in plots treated with AAL&K and Ceranock attract-and-kill bait stations and with conventional insecticides in three peach orchards in Tunisia. (a) the Alelcha orchard in 2013; (b) the Ouardanine orchard in 2013; and (c) the Morneg orchard in 2014. Values are means ± SE.

In the Alelcha and Ourdanine orchards, the proportion of fruit damaged at harvest was about two times lower in plots treated with Ceranock and AAL&K bait stations than in plots treated with conventional insecticides (fig. 2a,b).

In the Morneg orchard, the proportion of fruit damaged at harvest was substantially greater in plots treated with Ceranock and AAL&K bait stations than in plots treated with conventional insecticides (fig. 2c).

Non-target insects

The abundance of the different families of non-target insects did not significantly differ among treatments on 04 November 2013, which was before insecticides were sprayed and bait stations were deployed ($P = 0.954$). The abundance of non-target insects did significantly differ among treatments after 04 November 2013 ($P < 0.001$).

Chrysopidae abundance significantly differed among treatments in the Alelcha orchard ($P < 0.001$, table 2A) and in the Ourdanine orchard ($P < 0.001$, table 2B) and among sampling dates within the treatments (table 2A,B). Chrysopidae were more abundant in plots treated with Ceranock bait stations than in plots treated with AAL&K bait stations or with conventional insecticides at the Alelcha and Ouardanine orchards (fig. 3a,b).

Coccinellidae abundance significantly differed among treatments in the Alelcha orchard ($P = 0.0021$, table 2A) and in the Ouardanine orchard ($P < 0.001$, table 2B) and among sampling dates within the treatments (table 2A,B). Coccinellidae were significantly more abundant in plots treated with Ceranock bait stations than with AAL&K bait stations or conventional insecticides (fig. 3a,b).

Miridae abundance did not significantly differ in plots treated with Ceranock and AAL&K bait stations, but Miridae abundance was significantly greater ($P = 0.012$, table 2B) in plots treated with Ceranock and AAL&K bait station than in plots treated with conventional insecticides (fig. 3).

Discussion

In this study, *C. capitata* numbers were lower in two orchards with early-ripening varieties (in Alelcha and Ouardanine areas) than in an orchard with a mid-season variety (in the Morneg area). In the orchards with the early-ripening varieties, fruit damage and numbers of *C. capitata* males were twofold lower in plots treated with Ceranock and AAL&K attract-and-kill bait stations than in plots treated with conventional insecticides. The bait stations, however, were less effective than conventional pesticides in the orchard with a mid-season ripening variety and with high *C. capitata* numbers. We also found that Chrysopidae, Coccinellidae and Miridae families were more abundant in plots treated with Ceranock and AAL&K bait stations than in plots treated with conventional insecticides.

In Alelcha and Ouardanine orchards, *C. capitata* numbers were initially low (0.075 individuals/trap/day), increased (10.93 individuals/trap/day) with increasing temperature and fruit receptivity and then decreased to 0.91 individuals/trap/day at the end of

Table 2 Statistics derived from generalized linear models with Poisson error for the effects of treatment, date and their interaction on the abundances of non-target insects (Chrysopidae, Coccinellidae and Miridae) in the Alelcha orchard (A) and the Ouardanine orchard (B)

Taxa of non-target insects	Effect	d.f.	Deviance	Resid. d.f.	Resid. Dev	Pr(>Chi)
A						
Chrysopidae	Date	5	24.92	48	41.06	0.005
	Treatment	2	14.29	46	26.76	0.018
	Date × Treatment	10	23.40	36	3.36	0.002
Coccinellidae	Date	5	1.21	48	37.15	0.015
	Treatment	2	8.51	46	24.85	0.002
	Date × Treatment	10	9.46	36	7.84	0.074
Miridae	Date	5	2.34	48	24.31	<0.001
	Treatment	2	5.32	46	18.99	0.070
	Date × Treatment	10	9.14	36	4.59	0.155
B						
Chrysopidae	Date	5	37.72	48	32.90	<0.001
	Treatment	2	6.89	46	25.99	0.032
	Date × Treatment	10	14.22	36	11.78	0.163
Coccinellidae	Date	5	23.08	48	61.73	<0.001
	Treatment	2	21.16	46	40.57	<0.001
	Date × Treatment	10	35.66	36	4.91	<0.001
Miridae	Date	5	39.79	48	43.50	<0.001
	Treatment	2	8.96	46	34.55	0.011
	Date × Treatment	10	31.46	36	3.09	<0.001

the fruiting period because of harvest and the absence of other host fruits in the orchards.

In the Morneg orchard, *C. capitata* numbers remained low until the beginning of June. *C. capitata* numbers increased gradually as temperatures increased to about 29°C (Figure S1) and as host fruits, like those of figs and prickly pears, became available in nearby fields. *C. capitata* populations are greatly influenced by temperature and the presence of alternate host plants (Israely et al. 1997; Alemany et al. 2004; Campos et al. 2007). Thus, the low numbers of *C. capitata* observed in March, April and May under Tunisian conditions can explain why the attract-and-kill technique was effective in orchards with early-ripening varieties. Similar results were found by Bouagga et al. (2014), who reported that the use of Ceranock bait stations in Tunisian peach orchards reduced fruit damage by sevenfold compared to the untreated control. Khalaf et al. (2013) showed that the deployment of Ceranock bait stations decreased *C. capitata* numbers and fruit infestation in early ripening apricot. Reduced efficacy of attract-and-kill systems at high pest densities has been previously reported (Downham et al. 1995; Losel et al. 2000; Ebbinghaus et al. 2001). Other attract-and-kill systems have shown to be effective against *C. capitata* and other fruit flie species in other countries include the Magnet MED and the prototype L&K tube systems in Spain (Navarro-Llopis et al. 2013, 2014) and the GF-120 system in the USA (Prokopy et al. 2000). It would be useful to test these systems in citrus, peach and apricot orchards in Tunisia.

For early-ripening varieties, we showed that fruit damage caused by *C. capitata* was twofold lower in plots treated with either kind of bait station than in plots treated with conventional organophosphate insecticides (fig. 2). Other studies have also reported that the attract-and-kill technique is more effective than conventional insecticide sprays against *Bactrocera zonata* (Diptera: Tephritidae) in Mango orchards (Temerak et al. 2012) and against *C. capitata* in citrus orchards (Navarro-Llopis et al. 2010). The poor performance of AAL&K and Ceranock bait stations in terms of reducing *C. capitata* numbers and fruit damage in orchards planted with a mid-season variety suggests that AAL&K and Ceranock bait stations should be deployed at 400 and 500 bait stations per ha, respectively, when *C. capitata* numbers are very high. The performance of AAL&K and Ceranock bait stations might also be improved by deploying the stations earlier in the season to prevent *C. capitata* numbers from increasing to high levels later in the season. Early treatment was effective for the conventional insecticides in the orchard with the mid-season variety; at that orchard, insecticide treatments began on 19 March 2013 whereas bait stations were not deployed until about 2 months later. If the baits stations are deployed early, the lifespan of each kind of station should be considered.

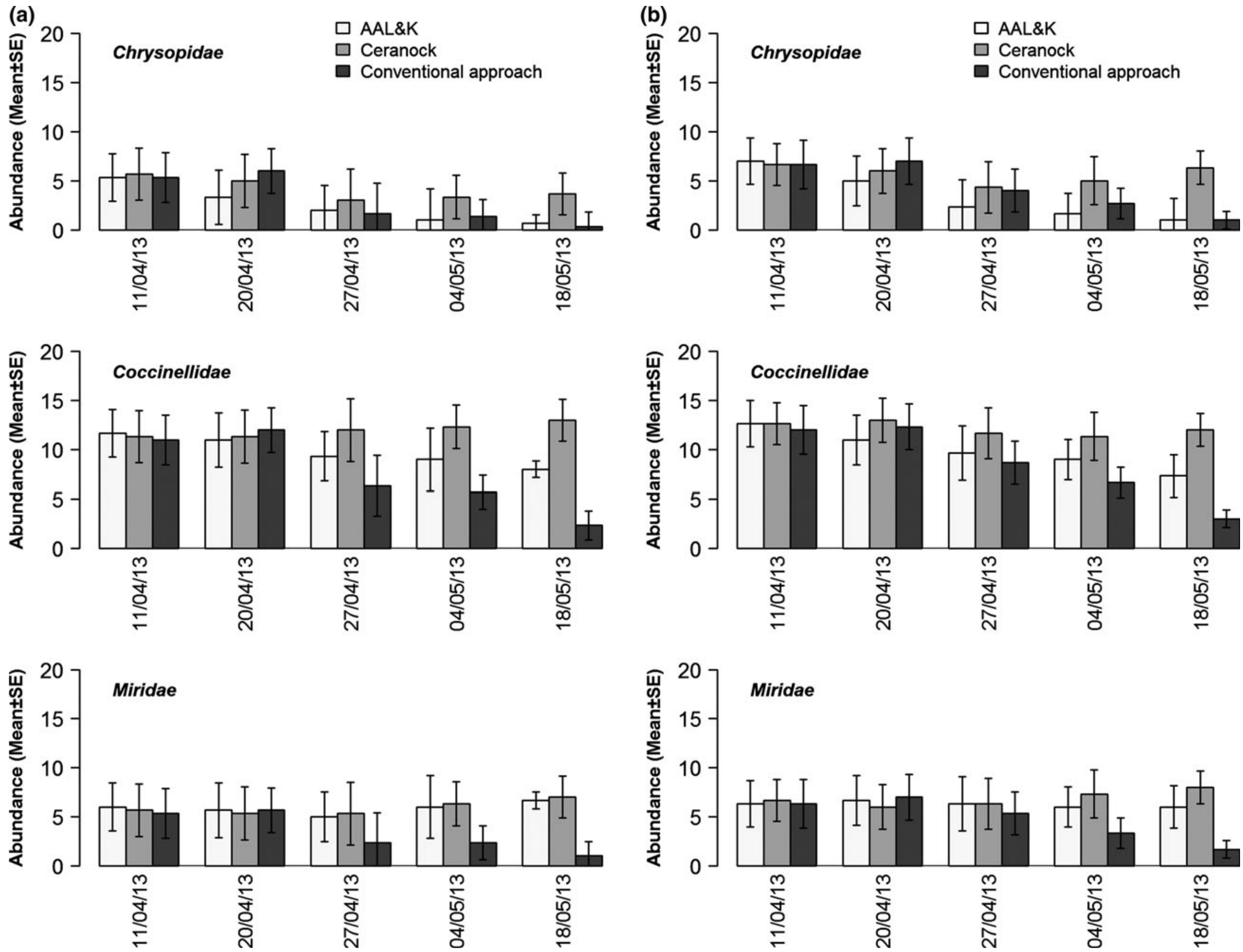

Fig. 3 Numbers of non-target insects (Chrysopidae, Coccinellidae and Miridae) in plots treated with AAL&K and Ceranock attract-and-kill bait stations and with conventional insecticides in Alelcha (a) and Ourdanine (b) peach orchards. Non-target insects were sampled with beat sheets, and values are means ± SE per tree.

In addition to effectively controlling *C. capitata* numbers and fruit damage in orchards planted with early-ripening varieties, the attract-and-kill bait stations caused less harm to non-target insects than conventional insecticides. Chrysopidae, Coccinellidae and Miridae were more abundant in plots treated with Ceranock and AAL&K bait stations than in plots treated with conventional insecticides (fig. 3). This can be explained by the absence of organophosphate cover sprays in the attract-and-kill technique. Organophosphate insecticides are known to negatively affect non-target organisms (Chang et al. 2013). In conventional control, which depends mainly on the application of broad-spectrum insecticides, non-target insects are exposed to acute and long-term toxic effects of insecticides directly via contact and/or indirectly via ingestion of contaminated prey (Bostanian et al. 2009). In attract-and-kill systems, the use of insecticides (the killing agent) is limited to the treated devices. As a consequence, attract-and-kill bait stations have minimal lethal and sublethal effects on non-target insects. The use of a pheromone should increase bait station selectivity (Katsoyannos et al. 1999) and should maximize the number of flies attracted and the lifespan of the dispensers (Navarro-Llopis et al. 2008).

Our study demonstrates that attract-and-kill bait stations are more effective than conventional insecticides for the control of *C. capitata* in peach orchards planted with early-ripening varieties. The bait stations also caused less harm to non-target insects than conventional insecticide applications. These results indicate that attract-and-kill bait stations represent a good alternative to conventional insecticide sprays for the control of *C. capitata* in Tunisian peach orchards planted with early-ripening varieties.

Acknowledgements

We thank the growers who kindly allowed us to conduct the trials in their orchards. We thank Russell IPM for providing the Ceranock devices, Atlas Agro for providing the AAL&K tubes and the technical team of the laboratory of entomology in the High Agronomic Institute of Chott-Mariem (ISA) for their help with the experiments. We also thank Frédéric Chiroleu for his help in statistical analysis, Héléne Delatte and two anonymous reviewers for their useful comments on the manuscript.

References

Alemany A, Miranda MA, Alonso R, Martin Escorza C, 2004. Efectividad del trampeo masivo de hembras de *Ceratitis capitata* (Diptera: Tephritidae) a base de atrayentes alimentarios. “Efecto-borde” y papel de los frutales abandonados como potenciadores de la plaga. Bol San Veg Plagas, 30, 255–264.

Barry JD, Vargas RI, Miller NW, Morse JG, 2003. Feeding and foraging of wild and sterile Mediterranean fruit flies (Diptera: Tephritidae) in the presence of spinosad bait. J Econ Entomol, 96, 1405–1411.

Bostanian NJ, Thistlewood HA, Hardman JM, Laurin MC, Racette G, 2009. Effect of seven new orchard pesticides on *Galendromus occidentalis* in laboratory studies. Pest Manag Sci, 65, 635–639.

Bouagga S, Nayem H, Ben-Hlima KM, Jammazi A, Djeoual K, AL-Zaidi S, 2014. Evaluation of attract and kill system to combat *Ceratitis capitata* on peach trees in Tunisia. J Agric Sci Tech, A4, 612–619.

Boulahia-Kheder S, Loussaïef F, Ben Hmidène A, Trabelsi I, Jrad F, Akkari Y, Fezzani M, 2012. Evaluation of two IPM programs based on mass trapping against the Mediterranean fruit fly *Ceratitis capitata* on citrus orchards. Tunisian J P Pro, 7, 55–68.

Burns RE, Harris DL, Moreno DS, Eger JE, 2001. Efficacy of spinosad bait sprays to control Mediterranean and Caribbean fruit flies (Diptera: Tephritidae) in commercial citrus in Florida. Fla Entomol, 84, 672–678.

Campos JM, Fibla Queralt JM, Martinez-Ferrer MT, 2007. Efecto de frutales aislados en las poblaciones de *C. capitata* en parcelas de citricos. Levante Agricola, 385, 100–106.

Chang LC, Il KC, Qing XL, Nicholas CM, Vargas RI, Ling C, 2013. A potential field suppression system for *Bactrocera dorsalis* Hendel. J Asia Pac Entomol, 16, 513–519.

Downham MCA, Mc-Veig LJ, Moawad GM, 1995. Field investigation of an attracticide control technique using the sex-pheromone of the Egyptian cotton leafworm, *Spodoptera littoralis* (Lepidoptera: Noctuidae). Bull Entomol Res, 85, 463–472.

Driouchi A, 1990. Evaluation économique des pertes causées par la mouche méditerranéenne des fruits: Cas de l’économie agricole Tunisienne Rapport de mission d’un expert consultant AlEA/FAO. Division de l’assistance technique et de la coopération, Tunisie.

Ebbinghaus D, Losel P, Romeis J, Cianciulli-Teller M, Leusch H, Olszak R, 2001. Appeal: efficacy and mode of action of attract and kill for codling moth control. Pheromones for insect control in orchards and vineyards. IOBC/WPRS Bull, 24, 95–99.

El-Sayed AM, Suckling DM, Byers JA, Jang EB, Wearing CH, 2009. Potential of lure and kill in long-term pest management and eradication of invasive species. J Econ Entomol, 102, 815–835.

Fauvel G, Atger P, Cotton D, Faivre AF, 1981. Etude de l’évolution des insectes auxiliaires et de leurs relations avec le psylle du poirier (*Psyllapyri* L.) et l’acarien rouge (*Panonychus ulmi* Koch) dans deux vergers du Sud-Est de la France en 1979. Agronomie, EDP Sci, 1, 813–820.

Gerson U, Cohen E, 1989. Resurgences of spider mites (Acari: Tetranychidae) induced by synthetic pyrethroids. Exp Appl Acarol, 6, 29–46.

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®. Acta Hort (ISHS), 1065, 1049–1056.

Israely N, Yuval B, Kitron U, Nestel D, 1997. Population fluctuations of adult Mediterranean fruit Flies (Diptera: Tephritidae) in a Mediterranean heterogeneous agricultural region. Environ Entomol, 26, 1263–1269.

Katsoyannos BI, Papadopoulos NT, Heath RR, Hendrichs J, Kouloussis NA, 1999. Evaluation of synthetic food-based attractants for female Mediterranean fruit flies (Diptera: Tephritidae) in Mc-Phail type traps. J Appl Entomol, 123, 607–612.

Khalaf MZ, Alrubeai HF, Al-zaidi S, 2013. Efficacy of Ceranock attract and kill system as a control method of Mediterranean fruit fly, *Ceratitis capitata* in apricot orchards in Central Iraq. J Agric Sci Tech, 3, 732–736.

Kroschel J, Zagarra O, 2013. Attract and kill as a new strategy for the management of the potato tuber moths *Phthorimaea operculella* (Zeller) and *Symmetrischema tangolias* (Gyen) in potato: evaluation of its efficacy under potato field and storage conditions. Pest Manag Sci, 69, 1205–1215.

Liquido NJ, Cunningham RT, Nakagawa S, 1990. Host plants of Mediterranean fruit fly (Diptera: Tephritidae) on the Island of Hawaii. J Econ Entomol, 83, 1863–1878.

Losel P, Penners G, Potting R, Ebbinghaus D, Elbert A, 2000. Laboratory and field experiments towards the development of an attract and kill strategy for the control of the *codling moth*, *Cydia pomonella* (L.). Entomol Exp Appl, 95, 39–46.

Magana C, Hernandez-Crespo P, Ortego F, Castanera P, 2007. Resistance to malathion in field populations of *Ceratitis capitata*. J Econ Entomol, 100, 1836–1843.

Manrakhan A, Kotze C, Daneel JH, Stephen PR, Beck RR, 2013. Investigating a replacement for malathion in bait sprays for fruit fly control in South Africa citrus orchards. Crop Prot, 43, 45–53.

Mansour M, 2009. Attract and kill for codling moth *Cydia pomonella* (Linnaeus) (Lepidoptera: Tortricidae) control in Syria. J Appl Entomol, 134, 234–242.

Martinez-Ferrer M, Campos JM, Fibla JM, 2010. Field efficacy of *Ceratitis capitata* (Diptera: Tephritidae) mass trapping technique on clementine groves in Spain. J Appl Entomol, 136, 181–190.

Michaud JP, 2003. Toxicity of fruit fly baits to beneficial insects in citrus. J Insect Sci, 3, 1–9.

Michaud JP, Grant AK, 2003. IPM-compatibility of foliar insecticides for citrus: indices derived from toxicity to beneficial insects from four orders. J Insect Sci, 3, 18.

Miranda MA, Alonso R, Alemany A, 2001. Field evaluation of Medfly (Diptera, Tephritidae) female attractants in a Mediterranean agrosystem (Balearic Islands, Spain). J Appl Entomol, 125, 333–339.

Navarro-Llopis V, Alfaro F, Domínguez J, Sanchis J, Primo J, 2008. Evaluation of traps and lures for mass trapping of Mediterranean fruit fly in citrus groves. J Econ Entomol, 101, 126–131.

Navarro-Llopis V, Domínguez-Ruiz J, Zarzo M, Alfaro C, Primo J, 2010. Mediterranean fruit fly suppression using chemosterilants for area wide integrated pest management. Pest Manag Sci, 66, 511–519.

Navarro-Llopis V, Primo J, Vasca S, 2013. Efficacy of attract-and-kill devices for the control of *Ceratitis capitata*. Pest Manag Sci, 69, 478–482.

Navarro-Llopis V, Primo J, Vacas S, 2014. Bait station devices can improve mass trapping performance for the control of the Mediterranean fruit fly. Pest Manag Sci, 71, 923–927.

Prokopy RJ, Wright SE, Black JL, Hu XP, Mc-Guire MR, 2000. Attracticidal spheres for controlling apple maggot flies: commercial orchard trials. Entomol Exp Appl, 97, 293–299.

R Development Core Team, 2008. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Temerak S, Lysandrou M, Moussa A, Chloridis A, Nagy P, 2012. Spinosad bait an organic creen bio-insecticide for the control of the Cucurbit fly *Dacus ciliatus* and the Peach fly *Bactrocera zonata* in Egypt. TJPP. 92.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Fig. S1. Mean temperatures between March and July in Alelecha and Ouardanine orchards in 2013 and in the Morneg orchardin 2014.