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Comparative efficacy of Malathion and spinosad bait sprays against *Ceratitis capitata* Wiedmann (Diptera: Tephritidae) in Tunisian citrus orchards

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Abstract
Malathion is the key insecticide used in the control of the Mediterranean fruit fly (medfly), *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae) in Tunisia. Resistance to this organophosphate insecticide has been reported in various insect species. The use of Malathion will slowly phase out and replaced by more environment friendly insecticides such as spinosad. In this study, we evaluated spinosad as a replacement of Malathion in bait spray to control *C. capitata* in Tunisian citrus orchards. The assessment was based on weekly monitoring of *C. capitata* males catches in traps baited with trimedlure and the estimate of fruit damage on the Maltaise variety. Our results showed that the population level was significantly lower in spinosad than in Malathion bait sprays with 1.6 and 15.30 fly/trap/day respectively. The effectiveness of spinosad treatment was confirmed by significantly low rates of fruit damage not exceeding 9.75 %.

Keywords: Citrus, Mediterranean fruit fly, Malathion, Spinosad, bait spray

Introduction
In Tunisia, citrus fruits are an important and valuable export commodity. Citrus culture is particularly important in the region of Cap Bon in North-eastern Tunisia. It is the main production area with about 15300 ha of citrus orchards [1] Tunisian citrus sector is restrained by several problems. Among these, the Mediterranean fruit fly (medfly) *Ceratitis capitata* Wiedemann is the most economically important insect pest among Tephritidae fruit flies which are well known for having economical importance since they affect a wide range of cultivated fruits [2]. In Tunisia, the economic damage caused by the medfly is estimated to be about 6.16 million USD [3]. Actually, the control of this pest remains problematic considering the severity of the caused damage.
In the last decades, many control techniques have been developed and implemented to manage the medfly including male annihilation, sterile male and chemical control with insecticide-baited protein hydrolysate. In Tunisia, most of the currently applied control schemes are mainly based on frequent applications of organophosphate based insecticides, especially Malathion mixed with protein-based baits (Lysatex) [4]. Malathion aerial sprays are very common. They are exclusively carried out by the Tunisian Ministry of Agriculture mainly during the period from September to November with an average of 3 sprays. Besides, many additional ground-malathion treatments can be performed by the farmers [5]. Resistance to Malathion has been reported in many insects' pests, including some dipteran pests [6] and *C. capitata* populations in Spain [7]. These insecticides have been found to have negative impacts on beneficial insects [8, 9] and can result in secondary outbreaks of other pests [10].The use of malathion will slowly phase out and replaced by more environment friendly insecticides such as Spinosad which may reduce insecticide residues in citrus fruit [11]. This insecticide has a better environmental profile and is less toxic to natural enemies compared to malathion [12, 13, 14]and showed a good control of different Tephritid pests worldwide [15, 16].
The aim of this study is to evaluate spinosad as a replacement for Malathion in bait spray to control *C. capitata* with regard to two parameters: monitoring of *C. capitata* populations and evaluation of fruit damage in Tunisian citrus orchards.

Materials and methods
Field sites
The study was conducted in citrus orchards planted with Maltaise variety from October to December 2011in three orchards located in the Cap Bon region, Tunisia in order to assess

spinosad as a replacement of malathion in bait spray to control *C. capitata*. The first orchard received three aerial applications with Malathion bait spays, the second received three aerial applications using Malathion bait sprays and one ground application using spinosad bait spray and the third orchard received only two grounds applications with spinosad bait spray. The record of different treatments applications is shown in Table 1.

Table 1. Records of application of ground and aerial treatments in different orchards

Orchards	Treatment	Active Ingredient (AI)	Ground/ Aerial application	Application number	Date of application
[3A*+0T**]	Malathion		Aerial	3	03/09/2011
		Malathion			13/10/2011
					14/11/2011
[0A+2T]	Spintor	Spinosad	Ground	1	16/10/2011
	Spintor	Spinosad	Ground	1	15/11/2011
[3A+1T]	Malathion	Malathion	Aerial	3	03/09/2011
					13/10/2011
					14/11/2011
	Spintor	Spinosad	Ground	1	10/09/2011

Population monitoring

In each orchard, five traps type Procida baited with cotton wicks soaked in trimedlure mixed with insecticide (dichlorodiphenyl phosphate (DDVP)) were hung in the south-eastern sides of 5 randomly selected trees at approximately 1.5 m above ground level. These traps were used to monitor the abundance of *C. capitata* male population in each orchard. Traps were checked weekly and the average number of captured males per trap per day was calculated and then used as a parameter reflecting the population density. Lures were renewed every four weeks.

Fruit damage assessment

In each of the three orchards, 10 trees were randomly selected and marked. From each one, 20 fruits from each side (East, West, North and South) were chosen. The number of oviposition punctures per marked fruit was counted weekly. For each tree, the rate of fruit damage was calculated as the number of fruit with at least one oviposition puncture over the total number of marked fruits.

Statistical analysis

For each orchard, the numbers of *C. capitata* males caught in traps were analyzed using a GLM (Generalized Linear Model) with Poisson error (Log link) as a function of treatment, date and interaction between these two factors. We then compared the curves of males' abundance during the experiment for the treatments by calculating area under disease progress curve (AUDPC) values, which were then analyzed using analysis of variance (ANOVA).

Rates of fruit damages were analysed using a GLM with binomial error (logit link) as a function of treatment, date and interaction between these two factors.

Results

Monitoring of *C. capitata* populations

Statistical analyses showed significant differences between *C. capitata* males abundance curves among the treatments ($F_{2, 12}$=105.86, P<0.001). *C. capitata* males abundance was affected by treatment ($Dev_{2, 87}$=3818.9, P<0.001), date ($Dev_{5, 84}$=325.8, P<0.001). No significant effect of interaction between treatments and date ($Dev_{10, 84}$=83.0, P=0.077) was observed. *C. capitata* male populations were significantly higher in orchards treated with three malathion aerial sprays than in orchards which received three aerial sprays with malathion andone ground application with spinosad and orchards which received only two ground treatments with spinosad. In orchards which received three Malathion aerial sprays, a maximum of 15.30 fly/trap/day was recorded in 16 November 2011 (Figure 1). While in orchards treated with three aerial sprays with Malathion andone ground application with spinosad and those which received only two ground treatments with spinosad, captures were 4 and 9 times lower with 3.70 and 1.6 fly/trap/day respectively.

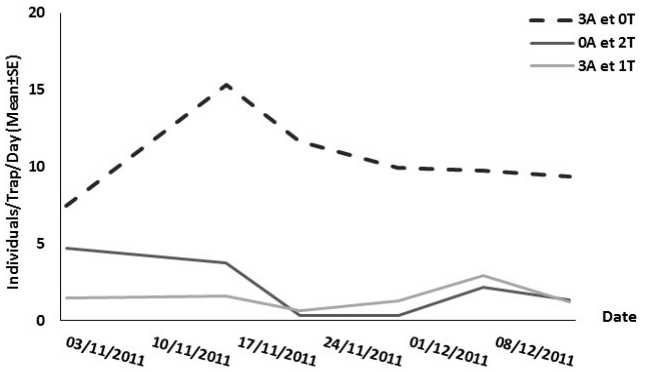

Fig 1: Weekly abundance of *C. capitata* males in Procida traps in the experimental citrus orchards (A: Aerial spray and T: terrestrial spray).

Fruit damage assessment

The rate of fruit damage was affected by treatment ($Dev_{2, 297}$=70.93, P<0.001) and date ($Dev_{5, 296}$=71.40, P<0.001). Significant effect of interaction between treatment and date ($Dev_{10, 294}$=1.66, P=0.43) was observed. Three weeks before harvest, the rate of damaged fruits increased as the fruit ripened and fruit damage in orchards with three malathion aerial sprays was significantly higher than in orchards which received three aerial sprays with malathion andone ground application with spinosad and orchards which received only two ground treatments using spinosad insecticides with 21.5, 11.75 and 9.75 % respectively (Figure 2).

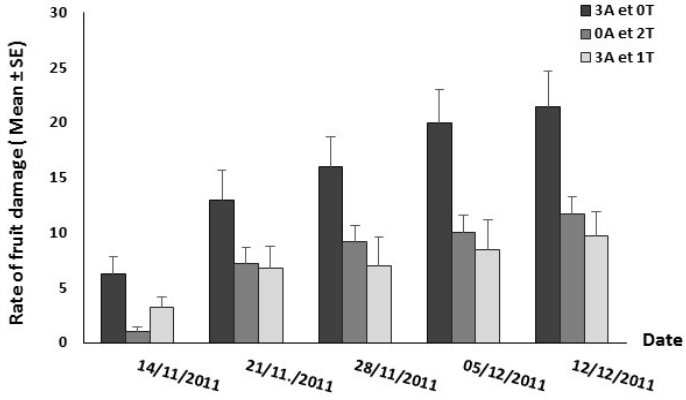

Fig 2: Accumulated percentage of soften oranges in the experimental *Citru*s orchards (A: Aerial spray and T: terrestrial spray).

Discussion

The results of our study showed that *C. capitata* populations were lower in orchards which received three aerial sprays with malathion and one ground application with spinosad and orchards which received only two ground treatments with spinosad than orchards treated with three malathion aerial sprays. Two ground applications of spinosad mixed with protein baits decreased significantly the population of *C. capitata* in citrus orchards and reduced two time the rate of fruit damage compared to orchards with 3 aerial applications of malathion bait spray or 3 aerial applications of malathion bait spray and one spinosad ground application.

The aerial application of Malathion bait spray can decrease the population of *C. capitata* but it remains above 10 individual/trap/day. In the orchard which received three aerial Malathion bait sprays and one ground spinosad bait spray, the population of *C. capitata* was lower than in that treated with three aerial Malathion bait sprays and one ground spinosad bait spray. The application of ground spinosad bait spray in 10 September 2011 suppressed the first populations of *C. capitata* emerged in citrus orchards which resulted in lower populations of the pest later in the season.

The lowest density of *C. capitata* population was recorded in orchards treated with two spinosad bait sprays demonstrates the efficacy of spinosad against *C. capitata* [11]. Laboratory essays, showed the efficacy of spinosad compared to Malathion in achieving a higher and faster mortality of *C. capitata* females. Spinosad baits spray were tested in the field in Hawaii and Florida and showed a good control of Tephritidae comparable to standard Malathion bait sprays [15, 17].

We showed that spinosad bait spray reduce twice the rate of fruit damage in Tunisian citrus orchards compared to aerial spray using Malathion. This has also been observed in other studies showing spinosad bait spray being more effective than Malathion bait spray against *C. capitata* [18], *Bactrocera dorsalis*, and *B. cucurbitae* [19].

Spinosad was found to be the most promising alternative insecticide to Malathion for use in combination with protein hydrolysate to control *C. capitata* and *C. Rosa* [20].In addition, spinosad could be used because of its relatively positive ecological profile [21]. No detectable residues of spinosad were found on fruit [1] and low toxicity of spinosad to honey bees and several natural enemies was observed [22, 23, 24].

Our study reports that spinosad is a good alternative to Malathion in bait spray. In order to maximize the efficacy of spinosad bait spray in the control of *C. capitata* in citrus fields, alternation of host plants such as figs and prickly pears should be well managed [25] and sanitation measures in the orchards should be implemented [26].

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