Efficacy of attract-and-kill devices for *Ceratitis capitata* control

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Abstract

BACKGROUND: The control of *Ceratitis capitata* Wiedemann used to rely on chemical control with organophosphate insecticides. New European Directives have banned the use of many substances, so the development of new control methods is essential to manage this pest. Bait sprays with spinosad, mass trapping and lure-and-kill techniques have been the basis for new integrated pest management programmes. This study planned two one-year field trials in two citrus areas to test the efficacy of attract-and-kill devices against mass trapping and spinosad plus bait treatments.

RESULTS: The Magnet® MED attract-and-kill device, Spintor® treatments and mass trapping achieved good control of *C. capitata* populations, confirmed by low percentages of damaged fruit in the harvest assessments. Conversely, the fly population levels on plots treated with another attract-and-kill prototype device increased three times more than the populations recorded in other treated plots. The same was observed for fruit damage, with from six to eight times less damage with Magnet® MED and spinosad treatments, respectively, vs. the attract-and-kill prototype devices.

CONCLUSION: With an effective attractant, conventional trapping systems can be replaced with cheaper, more user-friendly attract-and-kill devices. The efficacy of these devices and their advantages in relation to conventional mass trapping systems are discussed.

Keywords: *Ceratitis capitata*; attract and kill; bait station; mass trapping; fruit fly

1 INTRODUCTION

Currently, new *Ceratitis capitata* Wiedemann (Diptera: Tephritidae) control techniques are being studied and developed to replace traditional organophosphate pesticide applications. In Spain, fruit fly resistance to malathion has been reported[1] and insecticides such as malathion, fenthion or trichlorphon are currently banned in the EU. Replacement of organophosphates with other more environmentally friendly products, such as spinosad, is taking place. Spinosad formulations with bait (Spintor®) have proved to be as effective as malathion,[2] but some fruit damage problems were described in 2004 and 2005 in citrus and other crops when Spintor® was applied in spots (Alfaro, personal communication). In fact, scars appear at the point where the bait spot touches the fruit or the leaves.[3]

The use of attract-and-kill techniques has increased in recent years as these devices attract insects to a killing agent and avoid having to spray large quantities of insecticides to affect insects. The attract-and-kill tactic is called lure-and-kill when insects are not retained inside a device, whereas mass trapping refers to the use of a trap that retains pests.[4] Bait stations are defined as discrete containers of attractants and toxins whose insecticide attracts pests[5] but, in this case, the toxin can kill, sterilise[6] or infect the target insect. The application of bait sprays with insecticide should be considered as a lure-and-kill method, but with larger amounts of insecticide.[7]

In Spain, there are currently more than 50 000 ha of citrus being treated with bait, mass trapping or a lure-and-kill method because there are no other available environmentally friendly control methods. Bait stations are a cost-effective way of mass trapping which could replace current mass trapping methods. We should take into account that mass trapping costs around 3-4 euros per trap, which includes the trap, the attractant and the insecticide. This means a total amount of 200 euros per ha. This cost is not redeemable for most crops and only public subsidies enable the use of mass trapping. However, this cost can be cut to 2 euros per trap using bait stations (around 100 euros per ha), which means that this method can be applied to European crops cost-effectively.

Bait stations have been developed for other tephritids, such as *Bactrocera cucurbitae* (Coquillett) or *B. dorsalis* (Hendel);[8-10] *B. carambolae* Drew & Hancock,[11] *Rhagoletis pomonella* (Walsh),[12] *R. mendax* Curran,[13] *Anastrepha suspensa* Loew.[5] In most cases however, the efficacy of these devices has been tested in laboratory or field cages, but not under real conditions. Devices are designed to remain active in the field for as long as possible with no maintenance, and to attract flies effectively.

Both mass trapping and bait stations should be applied in isolated or wide areas in order to reduce fruit fly intrusion. It is intuitively obvious that immigration of pests into a treated area prevents their effective suppression or eradication.[14] For *C. capitata*, this intuitive affirmation is an even better example of such a case due to fruit flies' high mobility. In order to achieve "area-wide integrated pest management", trials should be carried out over large or very isolated areas, and should affect the whole population of this treated area during a long-term planned campaign.[14,15] For this reason, we planned field trials in plots of around 1 ha to monitor fruit fly populations and to assess the fruit damage in the centre of each plot.

This work reports the efficacy of two attract-and-kill devices with two parameters: fruit fly population reduction and fruit damage obtained with each treatment. The efficacy of these devices is compared with a standard treatment with insecticides and/or with the mass trapping technique. This study will allow the recommendation of alternatives to reduce the use of insecticides and to cut the cost of mass trapping systems.

2 MATERIAL AND METHODS

2.1 Field trials

Field trials were carried out in the years 2010 and 2011 in early-clementine orchards (*Citrus reticulata* Blanco, variety Marisol). All the traps or lure-and-kill devices (LK hereafter) were placed at a density of 50 traps ha^{-1} two months before the harvest started.

2.1.1 2010 Trial

Four treatments were assessed from mid-July to October 2010: two types of LK, Magnet® MED (Suterra LLC, Bend, OR, USA) and a new lure-and-kill device design developed in our laboratory (L&K Tube hereafter), mass trapping and spinosad spray. A field trial was carried out in a 20-year-old 7.6-ha orchard located in Sagunto (N 39º 39' 51''; W 0º 17' 31'', 20 km north of the city of Valencia, Spain). The orchard was divided into 12 plots, with three plots per treatment, as shown in Figure 1 and in Table 1. The untreated plots inside the orchard were non-productive plots or non-early varieties which ripen several weeks after Marisol clementines.

2.1.2 2011 Trial

Two treatments were assessed from mid-July to November 2011: Magnet® MED (Suterra LLC, Bend, OR, USA) and mass trapping. A field trial was carried out in a 18-year-old 7.3-ha orchard, located in Gandía (N 38º 58' 7''; W 0º 15' 59'', 60 km south of the city of Valencia, Spain). The orchard was divided into 8 plots, including three plots per treatment and two untreated plots, as shown in Figure 2 and in Table 1.

2.2 Description of treatments

Magnet® MED, supplied by Suterra Europe (Barcelona, Spain), is a paper envelope attract-and-kill device impregnated with deltamethrin which contains two membrane dispensers, with trimethylamine and ammonium acetate as attractants (Fig. 3A).

The L&K Tube is a prototype lure-and-kill device consisting of a yellow-coloured cylinder. There is a protein bait that contains cypermethrin at the bottom of the cylinder, and there are several small holes around the bait container which allow attractants to be released. There are two mesoporous dispensers inside the tube containing ammonium acetate, trimethylamine and methyl-pyrrolidine (Fig. 3B).

Mass trapping was carried out with Tephri-Traps®, baited with a three-component lure called Biolure® Unipack™ (Suterra LLC, Bend, OR, USA) and with a 500 mg dichlorvos strip (Suterra Biocontrol España, Barcelona, Spain).

"Spintor® cebo" is a commercial formulation from Dow Agrosciences LLC (Madrid, Spain) with 0.024 % w/v of spinosad in the protein bait. The product was diluted in three parts water and was sprayed in spots on the south face of trees with a backpack sprayer, using 1 L of "Spintor® cebo" per ha. In the 2010 field trials, plots 8, 10 and 12 (Fig. 1) were treated weekly from 5 weeks before harvesting until the end of the trials (from 2 September to 30 September).

2.3 Fruit fly population monitoring and fruit damage assessment

Two parameters were used in both the 2010 and 2011 trials to assess the efficacy of each treatment: fruit fly population and fruit damage assessment per plot.

In order to follow the fruit fly population, one monitoring trap was placed in each plot in the second week of July. Mosquisan® fly-traps (SANSAN Prodesing SL, Valencia, Spain) baited with Biolure® (Suterra LLC, Bend, OR, USA) and a 500 mg dichlorvos strip were employed for monitoring purposes. Traps were hung in the centre of each plot and were checked weekly in 2010 and biweekly in 2011, and the number of males and females caught were recorded.

Fruit damage was assessed for 4 weeks before harvesting when fruit began to ripen until the harvesting date. Twenty trees per plot and 20 fruits per tree were sampled weekly and scrutinised with a Linen Tester. The first and last three rows of each plot were discarded to avoid the influence of the outer population. The location of the trees selected for sampling was randomised before starting each assessment.

2.4 Statistical analysis

In order to analyse the fruit fly population data, two periods were established in the 2010 trial; the first from 21 July 2010 to the 7^{th} week of the trial (7 September), when attract-and-kill devices were placed in the field and no Spintor® treatments had yet been applied. The second period started from the 8^{th} week until the end of the 2010 trial, when fruits were ripening. Spintor® was applied weekly on the corresponding plots. In the 2011 trial, two periods were considered: an initial period before treatment application to ensure that all the plots had the same population; a second period started after traps were placed to assess the treatments' efficacy.

A one-way ANOVA was employed to compare the fruit fly populations in each period (LSD test at $P < 0.05$). The square-root transformation of the number of catches was used to normalise the data.

For fruit damage, a one-way ANOVA with the log-transformed data [log(x+1)] from the last two assessments was employed to compare the effect of the different treatments. Statistical analyses were done using the Statgraphics plus 5.1 package (Statpoint Technologies, Warrenton, VA, USA).

3 RESULTS

3.1 Fruit fly population

3.1.1 Trial 2010

According to the treatment employed, the fruit fly population dynamics is shown in Figure 4. During the first seven weeks, the medfly population increased in the L&K Tube plots, with significant differences found between the L&K Tube plots and the Magnet® MED and mass trapping-treated plots ($F = 15.21$; df = 3,83; $P < 0.001$) (Table 2). However, L&K Tube plots did not significantly differ from the Spintor® plots which, during this period, had not yet been treated. This means that mass trapping and Magnet® MED significantly reduced fruit fly populations in comparison to untreated plots. However, the L&K Tubes did not significantly reduce the fruit fly population if compared with an untreated field.

From the 7th week to the 10th week, corresponding with the ripening period, the Spintor®, Magnet® MED and mass trapping-treated plots showed no significant differences in population levels, whereas the population in the L&K Tube plots increased until the 10th week and became significantly higher than in the other plots ($F = 10.32$; df = 3,32; $P < 0.001$) (Table 2).

3.1.2 Trial 2011

At the beginning of the trial, before trap placement, no significant differences in fruit fly populations were noted between treatments (*F* = 0.1; df = 2,16; *P* = 0.90), according to the population dynamics depicted in Figure 5. In contrast, after placing traps and lure-and-kill devices, the fruit fly population increased in the untreated plots, with significant differences found with the Magnet® MED and mass trapping-treated plots (*F* = 8.28; df = 2,88; *P* < 0.001) (Table 3). This means that mass trapping and Magnet® MED significantly reduces fruit fly populations in comparison to untreated plots.

3.2 Fruit damage

3.2.1 Trial 2010

Fruit damage was assessed weekly from 8 September 2010, 4 weeks before harvesting, but no fruit damage was recorded until 29 September, 1 week before harvesting. Fruit damage evolution is shown in Figure 6. In the L&K Tube-treated plots, the number of damaged fruits increased as fruits ripened, whereas the fruit damage for other treatments remained at acceptable levels.

The fruit damage assessment during the harvest period is shown in Table 4. The L&K Tube plots displayed significantly more damage than the other treatments (*F* = 4.66; df = 3,284; *P* = 0.0034). Magnet® MED and mass trapping treatments proved to be as effective as weekly Spintor® sprays from the 5^{th} week before harvesting, with no significant differences among them.

3.2.2 Trial 2011

Although in this case, the fruit remained unharvested in fields for 1.5 months more than in the 2010 trials, fruit damage was below 0.05% in all the plots. This fruit damage was negligible and did not allow a statistical analysis.

4 DISCUSSION

This study has compared the efficacy of the mass trapping technique, attract-and-kill devices and bait sprays. In recent years, the mass trapping technique has proved to be as effective as insecticide sprays to control *C. capitata* in citrus orchards.[16,17] The results of this work confirm mass trapping efficacy and also show that attract-and-kill devices are effective enough to reduce *C. capitata* populations while remaining under the economic threshold. In fact, these devices had a similar efficacy as mass trapping or the Spinosad® weekly treatments. However, significant differences were found in the efficacy achieved by the different tested devices.

Two types of attract-and-kill devices were compared in the 2010 trial versus standard treatments, but there was no true control plot. The existence of this true control plot without treatments would provide information about pest pressure in the trial fields; unfortunately the cost of 3 ha of fruit losses would make the trial economically unfeasible. Nonetheless, the efficacy of new control methods can be compared with well-known treatments. Moreover in this trial, one of the treatments (L&K Tube) was significantly less effective than the others, with high percentages of fruit damage in the three plots where this treatment had been applied. These plots cannot be considered true control plots, but their high percentage of fruit damage and their significantly larger fruit fly population allow us to detect the strong pest pressure in this field and to validate the efficacy of the other control methods. With the 2011 trial, we could arrange three untreated plots because fruit damage was very low and no important economic losses were expected. On this occasion, we observed that *C. capitata* populations were 6 times higher in untreated plots than in the attract-and-kill plots.

A direct relationship between the percentage of fruit damage and the population level detected in monitoring traps was found for the 2010 data. In these trials, the female population reached 9.2 females per trap and day (FeTD) and fruit damage was over 1.5%. In accordance to this correlation, plots with smaller fruit fly populations (below 3 FeTD) had significantly lower percentages of fruit damage (under 0.3%). However in the 2011 trial, those plots with female populations over 6 FeTD did not present significant fruit damage, even though the fruit remained in the field and over-ripened for two months more than in the 2010 trial. The number of flies per trap and day (FTD) is an index that is widely used to establish Areas of Low Prevalence (ALPP).[18] With *C. capitata*, USDA and the Spanish Government agreed on a limit of 0.5 FTD to consider ALPP. However, there is no published FTD index to ensure that fruit damage remains below a defined limit. The results of the present work show that this index cannot be easily obtained.

Previous experiments carried out in 2009 demonstrated the good efficacy of the L&K Tube prototype in reducing fruit fly populations (unpublished results), with similar fruit damage reductions to those of insecticidal treatments. However, the efficacy of this device in the 2010 trials was significantly lower than in the chemical and mass trapping treatments. This difference between 2009 and 2010 could be attributed to the changes made in the devices tested, as the holes through which attractants are released had a different position. This fact means that the role of attractants is essential as to how the device performs and, therefore, any change made in how the device is manufactured must be tested under field conditions.

The mass trapping technique was as effective as the Magnet® MED treatment using a similar attractant. This means that, by using an effective attractant, a conventional trapping system can be replaced with a device that is cheaper and easier to handle. Moreover, the lifespan of Magnet® MED was 15 weeks, implying a lifespan of over 100 days; however, this observation should be confirmed in future trials.

The mass trapping technique has been employed for *C. capitata* control in Spain since the beginning of the 20th century.[19] The efficacy of this technique has been assessed in the last 80 years and its economic viability has been discussed in several articles.[17,20,21] Yet the most important improvements in this technique have come about through the development of synthetic female attractants,[22] and via the use of cheaper, more efficient traps.[23] Nevertheless, new improvements are required to prolong the lifespan of attractant dispensers. The dispensers for female attraction currently in use offer a lifespan of 4 months (Suterra LLC, Bend, OR, USA), whereas those for males can last 8 months in the field.[24]

The main advantages of the attract-and-kill systems over mass trapping techniques are: (1) less manpower required for their field application, (2) absence of an expensive device that retains flies, and (3) non-saturation of traps. In these trials, the assembly and hanging of traps, filled with attractants and insecticide, in mass trapping plots required 1.5 hour per ha, whereas the attract-and-kill systems needed about 40 min. In this case, the financial savings are more important for growers than the absence of insecticides.[4] The cost of the attract-and-kill treatment for 1 ha (50 devices ha^{-1}) has been estimated to be between 100 and 150 euros with 40 min manpower, whereas one Spintor® treatment takes 90 min and costs 18 euros per ha. By bearing in mind that the number of Spintor® treatments varies between three and six per year, the final cost would be between 48 and 96 euros and between 270 and 540 min manpower per ha. Currently, the cost of manpower in Spain is around 8 euros per hour; therefore, the mean cost of treatment in Spain would be around 130 euros per ha with attract-and-kill and 126 euros per ha with Spintor®. Therefore, the cost of the attract-and-kill technique would not prove to be an obstacle for the implementation and success of this control method.

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Figures

Fig. 1. Sketch of plot distribution in 2010 field trial. Plots: 1,3,6 Magnet Med; 7,9,11 Mass trapping; 8,10,12 Spinosad; 2,4,5 L&K tube.

Fig. 2. Sketch of plot distribution in 2011 field trial**.** Plots: 1,4,8 Magnet MED®; 2,5,7 Mass trapping; 3,6 Untreated

Fig. 3. Magnet MED® (A) and L&K Tube (B) devices

Fig. 4. Dynamics of fruit fly population according to treatment, as number of females caught per trap and day in 2010 field trial. Arrows point out treatments with spinosad applied only in Spintor® plots.

Fig. 5. Dynamics of fruit fly population according to treatment, as number of females caught per trap and day in 2011 field trial. Arrow points out mass trapping and Magnet MED® device placement**.**

Fig. 6. Dynamics of fruit damage in the different plots, as percentage of damaged fruit. Fruit damage assessments carried out on 23 September (1), 30 September (2), 7 October (3) and 14 October (4).

Tables

Table 1

Plot treatments and characteristics

2010				2011			
Plot #	Treatment	Size (ha)	# devices	Plot #	Treatment	Size (ha)	# devices
1	Magnet® MED	1.1	57	1	Magnet® MED	0.8	46
2	L&K tube	0.9	49	2	Mass trapping	0.9	48
3	Magnet® MED	1.3	73	3	Untreated	1.0	0
4	L&K tube	1.1	63	4	Magnet® MED	1.1	56
5	L&K tube	0.8	40	5	Mass trapping	0.8	45
6	Magnet® MED	0.9	46	6	Untreated	0.8	0
7	Mass trapping	0.3	14	7	Mass trapping	0.9	49
8	Spintor®	0.2	0	8	Magnet® Med	1.0	51
9	Mass trapping	0.4	24				
10	Spintor®	0.2	0				
11	Mass trapping	0.3	12				
12	Spintor®	0.3	0				

Table 2

Mean and standard error (±SE) of female *C. capitata* population registered in trial 2010.

Treatment	Females per trap and day (±SE)	
	21 July to 1 Sept. (weeks 1 to 7)	2 to 30 Sept. (weeks 8 to 10)
Magnet® MED	0.42 (±0.09)[a]	1.89 (±0.61)[a]
L&K Tube	2.76 (±0.39)[c]	7.94 (±1.29)[b]
Mass trapping	1.35 (±0.33)[ab]	2.38 (±0.42)[a]
Spintor®	2.73 (±0.74)[bc]	1.81 (±0.34)[a]

Means within a column followed by different letters are significantly different (LSD test at $P<0.05$).

The square root transformation of the number of catches was used to perform the ANOVA. Untransformed data are presented.

Table 3

Mean and standard error (±SE) of female *C. capitata* population registered in trial 2011.

Treatment	Females per trap and day (±SE)	
	22 June to 19 July	20 July to 9 Nov.
Magnet® MED	0.53 (±0.11)[a]	0.43 (±0.07)[a]
Mass trapping	0.58 (±0.18)[a]	0.40 (±0.05)[a]
Untreated	0.30 (±0.11)[a]	2.55 (±0.66)[b]

Means within a column followed by different letters are significantly different (LSD test at $P<0.05$).

The logaritmic transformation of the number of catches was used to perform the ANOVA. Untransformed data are presented.

Table 4

Percentage of fruit damage and standard error (±SE) according to treatment, during the harvest period, obtained in trial 2010.

Treatment	% Fruit damage (±SE)
Magnet® MED	0.21 (±0.12)[a]
L&K tube	1.18 (±0.47)[b]
Mass trapping	0.21 (±0.16)[a]
Spintor®	0.14 (±0.10)[a]

Percentages followed by different letters are significantly different (LSD test at P<0.05, with untransformed data).

The logarithmic transformation of the number of punctured fruits was used to perform the ANOVA. Untransformed data are presented