Female-biased mass trapping vs. bait application techniques against the Mediterranean fruit fly, *Ceratitis capitata* (Dipt., Tephritidae)

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Abstract

To develop new population control methods for the Mediterranean fruit fly, *Ceratitis capitata*, a study comparing bait application techniques (BAT) with a female-biased mass trapping strategy was carried out in seven citrus orchards in Mallorca (Balearic Islands, Spain). In the BAT treatment, fenthion, lambda-cyhalothrin and spinosad were applied separately in three of the orchards. In the other three, the mass trapping strategy (Probodelt traps baited with Biolure©) was adopted at a density of 50 traps/ha, reinforced when necessary with the same insecticide bait application (MTR). The seventh orchard was organically farmed and only mass trapping was used for control, but with a higher trap density (80 traps/ha). For pest monitoring, 2 traps/ha baited with Biolure© (for females and males) and 2 traps/ha baited with trimedlure (for males only) per orchard were inspected weekly. The most effective treatment was the MTR (with fenthion) programme, reducing the *C. capitata* female population by up to 68% [an average of 3.9 females/trap/day (f/t/d) were obtained vs. 12.6 f/t/d from BAT]. However, the lowest average *C. capitata* population (between the MTR programmes) was obtained by mass trapping supplemented with lambda-cyhalothrin (only 3.3 f/t/d). When only BAT was applied, applications with lambda-cyhalothrin proved to be the most effective (7.1 f/t/d). However, MTR carried out in the organic orchard resulted in the lowest female captures (2.0 f/t/d). Very little fruit damage was recorded in the treatment orchards. In all BAT treatments, the relative number of males and females was similar; however, in the MTR treatments fewer females than males were recorded in the same orchard.

Introduction

The Mediterranean fruit fly (medfly), *Ceratitis capitata* (Wiedemann), has been traditionally controlled with organophosphate insecticides, which are commonly associated with environmental problems. More recently, a number of effective alternatives are being pursued, such as mass trapping strategies and the sterile insect technique (SIT) (FAO/IAEA 1993; Hendrichs et al. 2002; Barnes et al. 2002). Mass trapping has been made possible through the development of a synthetic food-based female attractant, a highly selective and effective combination of three chemical compounds developed for attracting Mediterranean fruit fly females (Heath et al. 1997; Epsky et al. 1999; Miranda et al. 2001; Alemany et al. 2004a). In Spain and in other countries of the Mediterranean region, this female attractant (Biolure©)

has been very useful in mass trapping strategies in, e.g. peach (Sastre et al. 1999), custard apple (Ros et al. 2002), olive (Broumas et al. 2002) and citrus orchards (Alemany et al. 2004b). Bait application is a very useful method employed around the world to control different target insects, tephritids among them (Burns et al. 2001; Moreno and Mangan 2002), but sometimes has detrimental effects on non-target arthropods when toxic chemicals are used as the insecticides (Troetschler 1983).

The purpose of this experiment was to compare the effectiveness of a conventional insecticide bait application technique (BAT) with an integrated pest management programme based on mass trapping plus bait application in seven citrus orchards in Mallorca (Balearic Islands, Spain), with a view to reducing the use of harmful insecticide applications. In three of these orchards, the integrated pest management programme was conducted using a female-biased mass trapping strategy with a trap density of 50 traps/ha, but it was supplemented with insecticide applications (MTR) when trap catches exceeded the treatment threshold (1 male/trap/day), using either the organophosphate fenthion, the pyrethroid lambda-cyhalothrin, or the naturalyte spinosad. The BAT strategy was carried out in three other orchards using one of the same insecticides as in the MTR treatments. Spinosad, derived from a naturally occurring soil-dwelling bacterium, *Saccharopolyspora spinosa*, is an insecticide which has been shown to have minimal detrimental effects on natural enemy populations (Williams et al. 2003; Moreno and Mangan 2002), and its effectiveness in *C. capitata* control has been demonstrated (McQuate et al. 2005).

Results with MTR and only BAT were also compared with an intensified mass trapping programme (80 traps/ha) in a seventh citrus orchard that was farmed organically. Fruit damage caused by *C. capitata* was also assessed in all experimental orchards to aid in identifying treatment differences.

Materials and Methods

Field sites

Trials were conducted in seven commercial citrus orchards located at about 100 m above sea level on the central plain of Mallorca island. Annual rainfall was between 400 and 700 mm, the majority of which usually occurred during autumn. The climate in Mallorca is mild with an average temperature of about 20°C, although temperatures of up to 40°C can occur in summer, with occasional freezing conditions in winter. Experimental orchard sizes and details of the treatment regimes and trapping systems are given in table 1. It is relevant to mention that hens and ducks were active in the organic farmed orchard, probably contributing to the reduction in the *C. capitata* population by eating fallen oranges (and therefore any infesting larvae) and pupae in the soil. Maximum and minimum temperatures were recorded every week in each orchard.

Traps and attractants

Probodelt (U9901125, SEDQ, Barcelona, Spain) traps baited with a synthetic female attractant (Biolure©: ammonium acetate, trimethylamine and putrescine; Suterra, Lleida, Spain) were used for the mass trapping in the MTR programme. Two traps per hectare baited with Trimedlure© (TML) (Agri-Sense BCS Ltd, Pontypridd, Wales, UK) as a male attractant were also placed in each orchard. A 2.7 × 1 cm block of Vapona® strip (dichlorvos; Kenogard, Barcelona, Spain) was used in each trap as the retention mechanism, except in the organic orchard where it was substituted by a 32.5 × 1.0 cm section of a commercially available anti-tick dog collar (Scalibor©; Intervet Int., Boxmeer, the Netherlands) containing the pyrethroid deltamethrin, permitted in organic farming.

Table 1 Details of experimental orchards, treatment regimes and monitoring trap densities

Orchard no.	Area (ha)	Treatment	No. monitoring traps	
			Biolure	Trimedlure
1	0.70	Mass trapping + fenthion bait	35	1
2	3.74	Bait-only application (fenthion)	7	7
3	1.50	Mass trapping + lambda-cyhalothrin bait	75	3
4	2.66	Bait-only application (lambda-cyhalothrin)	5	5
5	2.69	Mass trapping + spinosad bait	135	5
6	4.50	Bait-only application (spinosad)	9	9
7	1.00	Intensified mass trapping	80	2

Mass trapping was at 50 traps/ha except in orchard 7 where it was 80 traps/ha.

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Treatments and population monitoring

The experiment was started during the last week of May 2007 and lasted 30 weeks, until the end of December. Table 1 shows the treatments and the number of traps used in each orchard.

In the BAT treatments, the insecticide in the bait mixtures was either fenthion, lambda-cyhalothrin or spinosad. The baits were made up as follows: 130 ml of fenthion 50% emulsifiable concentrate (EC) plus 130 ml of protein hydrolysate [Buminal 30%; Bayer-CropScience, Monheim, Germany, soluble concentrate (SL)] applied at a rate of 8–9 l water/ha; 60 ml of lambda-cyhalothrin 10% microencased suspension % (CS%) plus 300 ml of the same protein hydrolysate applied at a rate of 50 l water/ha; 1.25 l of spinosad [48% concentrated suspension (SC)] mixed with Buminal 30% SL at a rate 30 l water/ha. Fenthion and lambda-cyhalothrin applications were made by means of a tractor-driven spray pump, whereas spinosad was sprayed by a hand pump inserted into a bucket of the bait mixture. The first and third products were applied in the form of coarse 3–4 μm droplets, but lambda-cyhalothrin was sprayed with a droplet size of 0.5 mm, over a 1 m^2 area on the southern side of the canopy.

The MTR treatment included a combination of a mass trapping strategy supplemented with insecticide bait applied when the *C. capitata* population density exceeded the treatment threshold of 1 male/trap/day caught with TML. For mass trapping, traps in orchards 1 to 6 were placed at a density of 50/ha. In the organic orchard, because insecticide applications were not permitted, the density was increased to 80 traps/ha (intensified mass trapping). Traps were distributed uniformly within each orchard, although the density was increased on the borders because of the usually higher pest population density in those areas (Alemany et al. 2006). In total, 392 traps were placed in the trial orchards. To determine the seasonal population fluctuation of *C. capitata*, 4 traps/ha (two for males baited with trimedlure and two for females with Biolure) were monitored weekly, with males and females being recorded separately.

Traditional farming in the Balearic Islands included cultivation of alternative fruit fly hosts such as fig trees and prickly pear, which are used to feed pigs; and these trees are scattered almost throughout the territory. In an attempt to minimize the movement of *C. capitata* adults from poorly managed alternate fruit hosts (Alemany et al. 2004b), one trap baited with Biolure© was also placed in each fig tree (*Ficus carica* L.) and prickly pear bush (*Opuntia maxima* Miller) just before the fruits ripened. They were placed in orchards 2, 4, 6 and 7.

In order to properly judge the effectiveness of the pest management strategies tested, it is important to know the ratio of males to females in the fluctuating populations in the different treatments. For these reasons, catches with the male-only TML attractant were also taken into account.

Climatic variables

As all the experimental orchards were located in the same geographical area, possible differences caused by the influence of climatic variables were not taken into account.

Fruit damage assessment

To assist in identifying treatment differences, the percentage of fruit damage was also analysed. In each orchard, 10 randomly distributed trees per hectare were identified and sampled weekly, removing all fallen fruits beneath each canopy (a total of 176 trees). Fruits were collected separately for each orchard and taken to the laboratory where the fruit mass per orchard was recorded. The fruits were placed in buckets covered with gauze and inspected weekly for emergences, and maintained at room temperature and humidity to allow all infesting fruit flies to develop and emerge. All emerging *C. capitata* adults were recorded and the infestation expressed as numbers of flies emerged per 100 kg of fruit.

Statistical analysis

Data obtained included the number of insects captured every 2 weeks (females and males separately) on each of the seven orchards. Analysis of variance (ANOVA) (Statistics Trial 8; Stat Soft Inc., Tulsa, OK, USA) was used for verifying Gaussian or non-Gaussian distribution. The non-parametric Mann–Whitney U-test or t-tests were applied to compare captures over the 30-week monitoring period ($P < 0.05$).

Results

The relative success of the MTR and only BAT, and between common insecticide formulations, was evaluated by comparing the *C. capitata* population densities in each programme through the season, and the level of fruit damage in each treatment. 'Mass trapping' includes the use of bait only when considered necessary.

Monitoring of *C. capitata*

Mass trapping vs. bait application (active ingredient: fenthion)

Orchard 1: Mass trapping plus bait application.

The numbers of female and male *C. capitata* caught in the Biolure© traps are shown in fig. 1. It is evident that the mass trapping strategy alone (no additional bait applications) suppressed the development of the first population peak in June–July. The highest catches occurred in September–October (autumn) but decreased when a fenthion bait was applied. However, catches increased again rapidly in November, perhaps due to resistance. The average catch was 3.9 females/trap/day, with a maximum of 17.3 in early October (table 2).

Orchard 2: Four bait applications only.

Results are given in fig. 2. Despite early bait application, the *C. capitata* population rapidly reached a peak in June–July, decreasing later in summer as is usual in this region (Alemany et al. 2004a). The second application probably prevented a population increase but two smaller peaks occurred in autumn, followed by a decrease at the end of October after the third insecticide application. The third and fourth bait applications carried out by the farmer in November–December were clearly not necessary. The average trap catch in this orchard was 12.6 females/trap/day, with a peak of 45.3 in June (mid-summer) (table 2).

Mass trapping vs. bait application (active ingredient: lambda-cyhalothrin)

Orchard 3: Mass trapping plus three bait applications.

Mass trapping plus the bait applications reduced the *C. capitata* population to below the treatment threshold (1 male/trap/day) during the first half of the season (fig. 3). So mass trapping plus two bait applications prevented the development of the first population peak in summer, and greatly suppressed populations until autumn. A third bait was applied

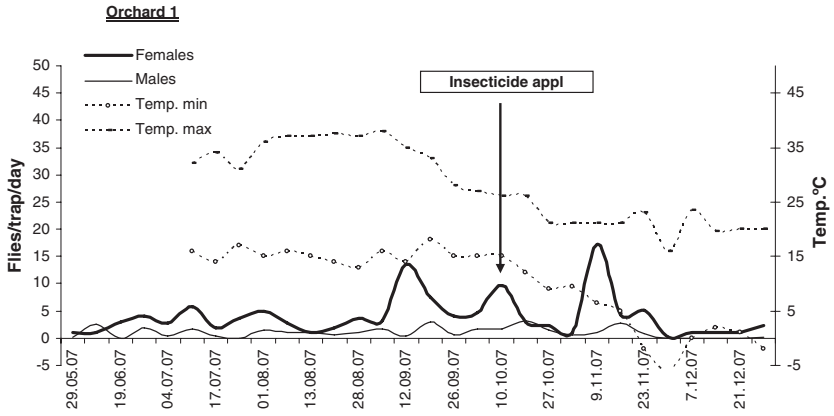

Fig. 1 Numbers of male and female *C. capitata* trapped in orchard 1 where mass trapping at 50 traps/ha was supplemented with fenthion when necessary. (Arrow indicates date of application: 10 Oct.) Maximum and minimum temperatures are represented.

Table 2 Average number of male and female *C.capitata* trapped per day under the different treatment regimes

	Mass trapping programme (MTR)			Bait-only application programme (BAT)		
Bait active ingredient	Orchard	♀/trap/day[1]	♂/trap/day[2]	Orchard	♀/trap/day[1]	♂/trap/day[2]
Fenthion	1	3.9 ± 3.8 a	19.2 ± 20.6 d	2	12.6 ± 13.6 b	12.9 ± 15.0 d
Lambda-cyhalothrin	3	3.3 ± 4.4 a	8.6 ± 12.9 cd	4	7.1 ± 5.8 ab	7.7 ± 7.8 cd
Spinosad	5	5.4 ± 4.8 a	7.0 ± 6.6 cd	6	14.9 ± 12.5 b	12.2 ± 8.6 d
No insecticide	7	2.0 ± 2.6	6.9 ± 6.5	–	–	–

[1]Traps baited with Biolure.

[2]Traps baited with trimedlure.

Mean values in each column followed of the same letter are not significantly different by ANOVA followed by Mann–Whitney U-test or t-tests ($P < 0.005$).

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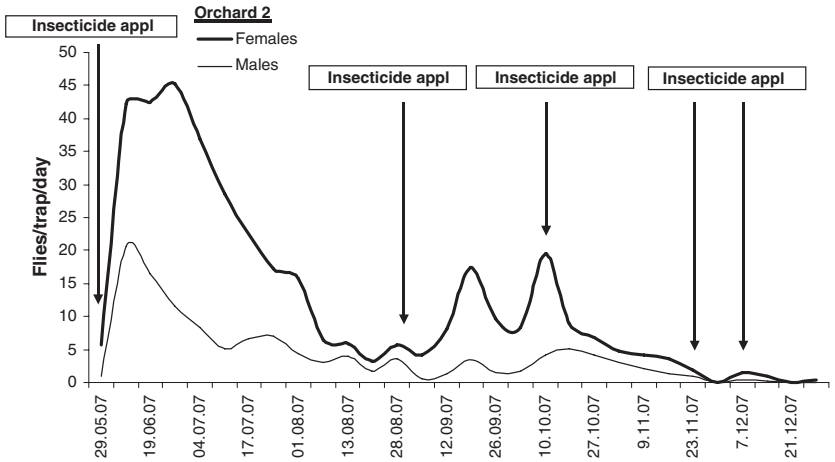

Fig. 2 Numbers of male and female *C. capitata* trapped in orchard 2 where only a bait programme using fenthion was applied. (Arrows indicate dates of application: 29 May, 29 July, 10 Oct., 23 Nov. and 7 Dec.)

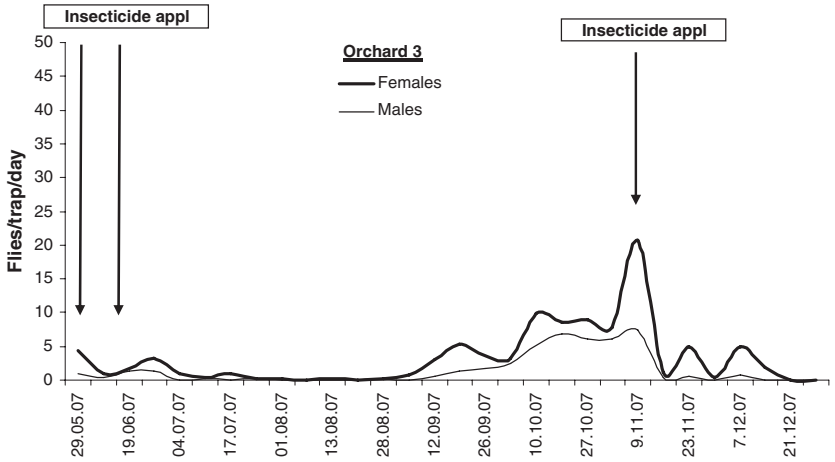

Fig. 3 Numbers of male and female *C. capitata* trapped in orchard 3 where mass trapping at 50 traps/ha was supplemented with lambda-cyhalothrin when necessary. (Arrow indicates date of application: 30 May, 18 June and 9 Nov.)

in autumn, which immediately reduced the population to low levels. The average trap catch was 3.3 females/trap/day, with a maximum of 20.8 in October–November (table 2).

Orchard 4: Bait applications only.

Figure 4 shows that the lambda-cyhalothrin bait applications appeared to have no long-lasting effect, with population peaks occurring throughout the season. The average trap catch was 7.1 females/trap/day, with two autumn peaks of 20.7 and 22.4 (table 2).

Mass trapping vs. bait application (active ingredient: spinosad)

Orchard 5: Mass trapping plus bait application. Results are presented in fig. 5. The *C. capitata* population increased moderately in June–July and after decreasing in late summer the usual autumn increase took place, but a spinosad application in October immediately reduced the population, after which low temperatures maintained it at low levels. Trap catches averaged 5.36 females/trap/day with a peak of 20.84 in October (table 2).

Orchard 6: Two bait applications only.

Despite the bait applications the *C. capitata* population fluctuated widely (fig. 6), with five significant peaks during the season. The average catch was 14.9 females/trap/day, reaching a peak of 43.7 late summer (table 2). The two bait applications may to a certain extent have suppressed the usually high autumn populations, but inadequately.

Orchard 7: Intensified mass trapping (80 traps/ha) only.

No insecticide applications were permitted in this organic orchard. *C. capitata* populations were the

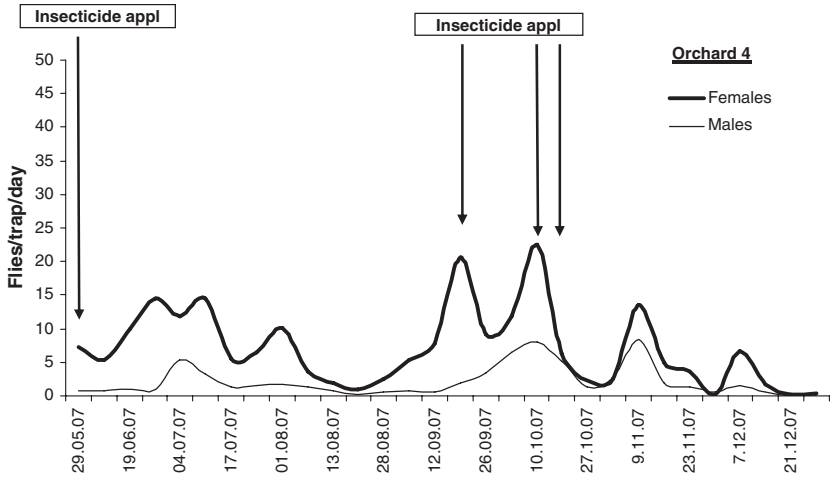

Fig. 4 Numbers of male and female *C. capitata* trapped in orchard 4 where only a bait programme using lambda-cyhalothrin was applied. (Arrows indicate dates of application: 29 May, 20 Sep., 10 Oct. and 23 Nov.)

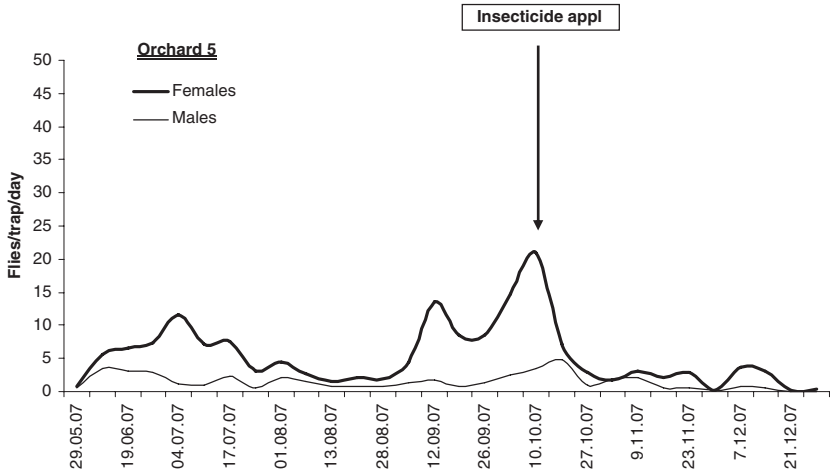

Fig. 5 Numbers of male and female *C. capitata* trapped in orchard 5 where mass trapping at 50 traps/ha was supplemented with spinosad when necessary. (Arrow indicates date of application: 10 Oct.)

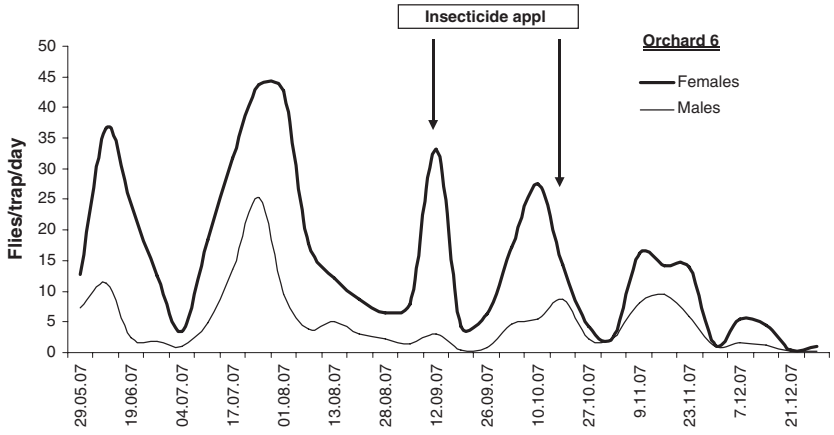

Fig. 6 Numbers of male and female *C. capitata* trapped in orchard 6 where only a bait programme using spinosad was applied. (Arrows indicate dates of application: 11 Sep. and 19 Oct.)

lowest of all the seven treatments (fig. 7), with an average catch of 2.0 females/trap/day and a peak of only 8.6 (table 2). Nevertheless, it should be pointed out that, as commented before, hens and ducks that were moving freely in the orchard, probably contributed actively to the reduction of the *C. capitata* population by eating fallen infested oranges and pupae in the soil.

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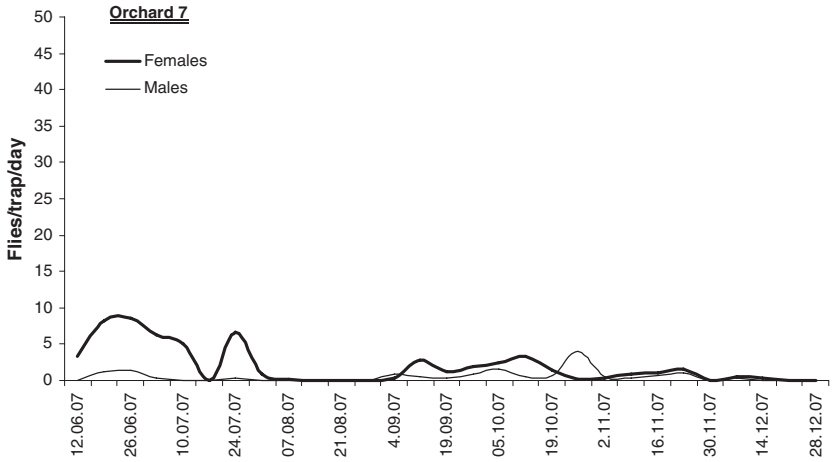

Fig. 7 Numbers of male and female *C. capitata* trapped in orchard 7 (an organic orchard) where only intensified mass trapping at 80 traps/ha was carried out.

Male catches with trimedlure traps

Ceratitas capitata trap catch data with the male-only TML attractant are given in table 2; also given are the female (and male) catch data with Biolure attractant. When comparing treatments it should be noted that in BAT the female : male ratio was always close to 1 : 1, whereas in MTR the mean number of females caught was always significantly lower than that of the males. The greatest reduction in the female population using insecticide applications was achieved with mass trapping (using the synthetic female-biased attractant Biolure) with bait applications incorporating lambda-cyhalothrin. However, the lowest female captures were obtained by means of the intensified mass trapping (80 traps/ha) carried out in the organic farm without any bait insecticide application. The total number of flies captured and the percentage of females caught in Biolure traps vs. trimedlure traps in all seven orchards are given in table 3.

Table 3 Total number of flies captured and percent females in Biolure traps vs. trimedlure traps in all seven orchards

	Traps baited with Biolure		Traps baited trimedlure	
Orchard	Total number of flies	% females	Total number of flies	% females
1	1112	78.7	4520	4.1
2	27 022	76.2	24 277	6.9
3	3141	70.1	5664	0.6
4	10467	77.1	9151	7.9
5	7574	77.2	7950	2.2
6	39112	75.3	25 280	4.8
7	1085	77.6	3018	1.2

Influence of unmanaged fruit hosts (*Ficus carica* and *Opuntia maxima*) on the *C. capitata* population density

Captures obtained with Biolure-baited traps placed on the fig tree canopy and prickly pear trees once again showed the importance of the poorly managed *C. capitata* fruit hosts as pest multipliers. The median number of captures during the ripening of fruits was 3.2 females/trap/day, which reached a maximum of 8.7 females/trap/day in orchard 1.

Fruit damage assessment

A total of 51.42 kg of fallen oranges was collected from beneath the 176 selected trees. The degree of infestation by *C. capitata* was very low throughout the trial and no significant differences between treatments were found, the highest rate of emergence being 0.54/kg of fruit (orchard 2). Not infestation was found in the mass trapping orchards where either lambda-cyhalothrin or spinosad was applied, and nor in the organic orchard.

Discussion

Several years ago, mass trapping was shown to be a very effective pest management tool (Sastre et al. 1999; Ros et al. 2002; among others), and today it is used to control several species of insect pests (Navarro et al. 2008). Alemany et al. (2004b) showed that a female mass trapping strategy with a high trap density (1 trap every two trees) was able to control *C. capitata* even at high population levels. On the other hand, because of the high cost of traps in mass

trapping programmes, only 50 traps/ha are normally used; however, they are not effective enough in our region because of the high *C. capitata* population density. Hence, farmers prefer to apply the more economic and conventional bait spray applications.

Considering the data from all seven orchards in this trial, we conclude that the MTR programme of mass trapping of females with 50 traps/ha, supplemented when necessary with one of three insecticide bait formulations, was more effective in reducing *C. capitata* females in citrus orchards than the bait-only programme (BAT) when comparing the same insecticide, always showing significant differences. The mass trapping plus fenthion reduced the female population by up to 68% when compared with bait-only applications, followed by the spinosad treatment (64%).

The lowest average *C. capitata* population in the TMR programmes was obtained with mass trapping supplemented with lambda-cyhalothrin. However, in the BAT programme, this insecticide only reduced the female population by 50%. Using BAT, the greatest reduction in the female population was obtained with lambda-cyhalothrin.

The organic orchard with intensified mass trapping and no insecticides had the lowest *C. capitata* populations. This is possibly due not only to the higher density of traps (80/ha) but also perhaps to the hens and ducks in the area feeding on fallen fruit and fruit fly pupae in the soil. This fact once again demonstrates the advantages of environmental organic farming management. On the other hand, when compared between bait-spray applications only the highest reduction in female population was recorded for lambda-cyhalothrin (7.3 females/trap/day).

Results obtained recommend that the organophosphate fenthion be substituted for or alternated with lambda-cyhalothrin. Alternatively, despite its short residual effect in the field, spinosad could be used because of its positive ecological profile (e.g. Thomas and Mangan 2005).

An important factor in the management of *C. capitata* is the occurrence of lots of poorly managed alternate host plants such as figs and prickly pears, which are widespread in Mallorca (Alemany et al. 2004b, 2008). As these act as important reservoirs of fruit fly infestation which can complicate Mediterranean fruit fly management in commercial citrus plantings, traps baited with female attractants should be placed in the canopies just before fruit ripening.

In the bait-only treatments, the ratio of males (trapped with TML) to females (trapped with Biolure©) in the same orchard was similar, while in the mass trapping treatments the ratio of females to males in the same orchard was much lower. This could be expected because mass trapping using Biolure © is biased towards trapping females. This is a critical factor in fruit fly management because of the importance of reducing the number of females and therefore the number of eggs laid.

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