JOURNAL OF APPLIED ENTOMOLOGY

J. Appl. Entomol.

Field efficacy of *Ceratitis capitata* (Diptera: Tephritidae) mass trapping technique on clementine groves in Spain

M. T. Martinez-Ferrer, J. M. Campos & J. M. Fibla

IRTA Amposta, Carretera de Balada, Amposta, Tarragona, Spain

Keywords
citrus, medfly, trap density, varieties

Correspondence
M. T. Martinez-Ferrer (corresponding author), IRTA Amposta. Carretera de Balada, Km 1. E-43870. Amposta, Tarragona, Spain.
E-mail: teresa.martinez@irta.es

Received: November 29, 2010; accepted: February 17, 2010.

doi: 10.1111/j.1439-0418.2011.01628.x

Abstract

Mass trapping is being used in Mediterranean regions to control *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae) in citrus. The technique is based on placing a high density of traps with an attractant (Ferag CC D TM®, a three-membrane dispensers of trimethylamine, ammonium acetate and diaminoalkane), and a toxicant, aiming to capture the highest numbers of adults in the grove. From 2006 to 2008, field trials were conducted in commercial Clementine (*Citrus reticulata* Blanco) groves to evaluate the efficacy against medfly of using different trap densities, 25, 50, 75 and 100 traps per ha. Based on the number of adults captured, fruit maturity parameters and medfly fruit damage, a 25 trap per ha density appears to be a valid stand-alone method to protect mid-season varieties (Clemenules) from the attack of *C. capitata*, because <0.5% of fruits on average were damaged at harvest. For early-season varieties (Loretina and Marisol), mass trapping technique alone did not offer a satisfactory medfly control, because medfly populations were higher in the warmer months of the early-season variety production, which led to a higher percentage of attacked fruits, even when increasing the trap density from 50 to 100 per ha. However, using 50 traps per ha density combined with chemical treatments only to the perimeter row of the grove gave good results, because <2% of fruits in average were damaged at harvest.

Introduction

Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae), is one of the most serious pests in the world, as it is highly polyphagous and attacks more than 300 different species (Christenson and Foote 1960; Liquido et al. 1990). Unless treated, it is believed that more than 30% of fruits in Spain would be attacked (Primo 2004).

About 5 million tonnes of citrus are produced annually in Spain, and Clementines (*Citrus reticulata* Blanco) represent 27% of the total, or approximately 1.5 million tonnes.[1] In Eastern Spain, Clementine represents about 50% of citrus production.[1] In citrus, *C.capitata* mainly causes damage to early-ripening varieties, such as Clementine. As these fruits generally start to ripen in September, it is from this moment on that they are sensitive to *C. capitata* attacks. Currently, organophosphates (e.g. chlorpyrifos-methyl), and pyrethroids (e.g. lambda-cyhalothrin), and Spinosad mixed with protein baits are applied in both aerial and terrestrial treatments to control medfly populations. Other techniques are being developed, such as the sterile insect technique, chemosterilant, biological control with parasitoids, mass trapping or the combination of several of these methods (Navarro-Llopis et al. 2004). As insecticides are applied near harvest to control this pest, there is a high risk of pesticide residues on fruit at harvest,

[1](http://www.intercitrus.org/NdSite/OnLineCache/FMS/89/06/236b9b91ac24ed98c8b2de5f5dac1082/008%20Prod.pdf)

as well as significant negative effects on the natural entomophagous of citrus agrosystem which can result in secondary outbreaks of other pests, such as Tetranychidae mites (Gerson and Cohen 1989). Up to eight sprays can be performed in a grove to control medfly in a season (Chueca 2007). However, performing chemical treatments does not normally guarantee that fruit losses will be avoided.

The mass trapping system attempts to provide a successful pest control, while preventing the problems pointed out earlier. This technique aims to reduce as much as possible the foraging adult medfly population in the area, by hanging on trees traps baited with lures and toxicants to catch them. Several studies have proved the efficiency of this method (Agunloye 1987; Ros et al. 2002; McQuate et al. 2005) for several fruit tree species. Recent studies demonstrate that the International Pheromone McPhail Trap baited with Biolure (three-component food-type attractant) is highly efficacious in capturing adult medfly (Gazit et al. 1998; Katsoyannos et al. 1999; Katsoyannos and Papadopoulos 2004). The combination of Probodelt traps with Trypack or Ferag CC D TM attractants also provided satisfactory results in stone fruit orchards (Batllori et al. 2005).

In Spain, more than 30 000 ha of citrus groves are protected against medfly by mass trapping. Good efficacy has been achieved using 50 traps per ha hung to trees 3 months before harvesting (Navarro-Llopis et al. 2008). The objective of this paper was to validate the efficacy of this method on different Clementine varieties and optimize the trap density required to successfully control this pest.

Materials and Methods

Groves and trapping scheme

Experiments were carried out in 2006, 2007 and 2008 in nine commercial groves, three per year, of citrus Clementines (*C. reticulata* Blanco cv. Clemenules, Loretina and Marisol), located in Traiguera (Castellón province) (40°34′ 31.38″N, 0°22′ 27.60″E), Bítem (40°51′ 32.05″N, 0°31′ 49.17″E) and Alcanar (40°31′ 21.08″N, 0°27′ 59.16″E) (Tarragona province). Location of groves and varieties were representative of the citrus-growing area, and we considered the years as replicates. Each grove was approximately 3 ha in size, planted regularly at 416 trees per ha (6 × 4 m) and drip irrigated. Clemenules is considered a mid-season variety that is harvested from November to January. Loretina and Marisol are considered early-season varieties, with a harvest period from September to late October. Until the beginning of the experiment, groves were sprayed as usual to control pests, mainly aphids, diaspididae and tetranychidae mites. During the trials, the number of medfly adults caught in traps, the rind colour evolution and the percentage of punctured fruits were recorded weekly in each plot. According to these data, no insecticide treatments were applied while the trial was performed in Clemenules groves. In the other two varieties, treatments against medfly were performed, given in table 1. Sprays were made to the entire plot or only to the perimeter row. All the treatments were applied to the whole grove, so the different trap densities plots underwent the same treatments. In 2006, Loretina grove was excluded because treatments were not similar for the entire grove.

Each grove was divided into three plots of 1 ha approximately, and each plot was randomly assigned a different trap density: low, medium and high, corresponding to 25 (D25), 50 (D50) and 75 (D75) traps per ha in Clemenules groves and 50 (D50), 75 (D75) and 100 (D100) in Marisol and Loretina groves. Distance between plots ranged from 25 to 50 m. Probodelt® (Maxitrap® model; Amposta, Tarragona, Spain) traps with Ferag CC D TM® (SEDQ, Barcelona, Spain) attractant (three-membrane dispensers of trimethylamine, ammonium acetate and diaminoalkane) were homogeneously hung on the trees. DDVP was used as toxicant. Traps were placed in late August and early September in the Marisol and Loretina groves (31/8/2006, 28/8/2007 and 2/9/2008) and in late September and October in the Clemenules groves (20/10/2006, 9/10/2007 and 25/9/2008), 1.5–2 months before harvesting, on the

Table 1 Chemical treatments sprayed to the citrus groves during the study period

	Marisol	Loretina
2006	1 × Malafin® 0.35% (W) (a)	
2007	1 × Malafin®0.35% (W) (a) 1 × Malafin®0.35% (P) (a)	6 × Spintor Cebo® 3.3% (P) (b) 1xKarate Zeon® 0.1% + NuLure® 0.5% (W) (a)
2008	1 × Malafin® 0.35% (W) (a)	6 × Spintor Cebo® 3.3% (P) (b) 1 × Malafin® 0.35% (W) (a)

(W): Whole grove; (P): Perimeter row; (a) 1000 l/ha; (b): 10 l/ha. Spintor Cebo (Spinosad 0.024% [CB] P/V; Dow AgroSciences, LLC, Indianapolis, IN); Karate Tecnologia Zeon (Lambda Cihalotrin 10% [CS] P/V; Syngenta Agro, S.A., Madrid, Spain); NuLure Insect Bait (Hydrolyzed protein 30% P/V; Agrichem, S. A., Madrid, Spain); Malafin emulsionable (Malathion 50% p/v. EC P/V; Agrodan, S.A., Madrid, Spain).

trees at a height of 1.5–2 m from the ground. They were hung in a shaded part of the canopy facing south, homogeneously distributed throughout the groves at the corresponding trap density. Attractants were not replaced, as its useful life is a maximum of 120 days (Escudero-Colomar et al. 2008), and our experiments lasted <60 days.

Meteorological data were obtained from the nearest three stations located in surrounding areas of the tested groves. The average temperatures from these three stations were used to compare among years.

Colour index determination

The *L* (0–100, black to white), *a* (yellow/blue) and *b* (red/green) Hunter laboratory parameters of the colour system were measured with a Minolta CR-400® Chroma Meter (Konika Minolta, Osaka, Japan). The data reported are the result of the 1000 *a*/*Lb* transformation (CCI) that displays negative and positive values for green and orange colours, respectively, in citrus fruits. In this transformation, the zero value coincides with the mid-point of the colour break period (Jiménez-Cuesta et al. 1981). The colour index of a single fruit was the average of four measures around the equatorial plane of the fruit, and one on the stylar end area, and was repeated for a total of 100 fruits per plot randomly selected. The resulting plot average is then of 500 colour measures. Determinations were carried out, weekly or fortnightly, depending on colour fruit, from early September to the end of November. The colour index determination was performed the 3 years not only in the experimental groves, but also on several commercial Clementine groves in this citrus-growing area.

Adults captured in traps

From 24 to 105 traps per plot (in 2006 and 2007: 24; in 2008: all the traps) were checked once a week. All of the *C. capitata* adults captured in the traps were counted and separated according to sex. Adults were removed after each sampling. For 2007 and 2008, adults were analysed separately, depending whether the traps were located in the perimeter row or in the rest of the grove.

Internal maturity of fruits

To check the maturity of fruits, titratable acidity and total soluble solids (TSS) of the juice were analysed. Acidity was determined by titration with 0.1 N NaOH on 10 ml of juice diluted with 10 ml of H_2O. The results were expressed in gram citric acid per 100 g of fresh weight (FW). TSS were determined by measuring the refractive index of the same juice with a hand refractometer (Shibuya Optical Co. Ltd, Tokyo, Japan) and the results expressed as percentages (g per 100 g FW). TSS/acidity rate (E/A index) was used as a maturity index as generally described in citrus. Determinations were carried out the first week of October in Marisol, the second in Loretina and the first week of November in Clemenules on 30 fruits per plot randomly selected.

Fruit damage assessment

Evaluations of fruit damage caused by *C. capitata* were carried out prior to harvest. A total of 900 fruits per plot, selected from 45 random trees (25 trees from the centre and 20 from the perimeter, 20 fruits per tree selected randomly), were visually inspected on each sampling date. The percentage of fruit attacked by *C. capitata* was recorded. Trees were chosen randomly in the plot, separating the perimeter row for the statistical analysis. Dates of sampling were the first and the second weeks of October and the first week of November, respectively, for Marisol, Loretina and Clemenules varieties, according to their ripeness.

Statistical analysis

Statistical analysis was performed by analysis of variance (PROC General Linear Model, SAS Institute Inc. SAS/STAT 1998). Data that did not meet the normality and homoscedasticity assumptions were transformed as appropriate (the percentage of attacked fruits data were transformed to arcsine and the number of adults captured to square root) before analysis (Sokal and Rohlf 1981). Means were compared using Duncan's multiple range test with a 95% significance level.

Results

Quality parameters and colour progress of fruits

During the first week of November for Clemenules, and the first and second weeks of October for Marisol and Loretina varieties, respectively, the E/A index in 2006, 2007 and 2008 was higher than 6.5 (table 2). Therefore, according to commercial quality parameters required in citrus oriented to foreign markets, fruits were suitable to harvest (Martínez-Jávega et al. 1995).

The progress of rind colour followed similar patterns on Marisol and Loretina varieties (fig. 1). By the third week of September, the CCI of these varieties reached −15. This value indicated that fruits could be harvested and exposed to post-harvest degreening treatments in ethylene chambers. In the Clemenules variety, the colour shift from green to orange occurred later than on the other two varieties, and CCI's value −15 was achieved on the second week of October. In the 3 years, the early-season varieties were harvested the first fortnight of October and the mid-season variety, Clemenules, during the first week of November. In the three varieties and years, harvest coincided with the moment when CCI was between −5 and −10. At this moment, although fruits had not reached a totally orange colour, they were directly marketable, with no need for artificial degreening.

Adults captured in traps

To compare the evolution of adults captured in traps, depending on varieties and years, the capture data in the D50 plots of all groves were analysed. For all the years and groves, adult population decreased with fall temperature decline, (figs 2 and 3). At the beginning of November, population was reduced to values below 0.5 adults per trap and day in all the years and varieties. The maximum of captures per trap and day in 2006 was about 11, 6 and 1.2 in Loretina, Marisol and Clemenules groves, respectively, whereas in 2007 these maxima were about 1.4, 1 and 0.3, respectively, and in 2008, 0.9, 1.3 and 0.3, respectively.

In both early-season varieties, Marisol and Loretina, adult abundance reached a maximum at the end of September and the beginning of October. At this moment, the rind colour (CCI) was between −15 and −10. Adult abundance started diminishing from October, and this decrease was more pronounced at the end of October. In general, captures on the perimeter row were higher than on the rest of the plot in all varieties and years. For Marisol and Loretina varieties, medfly captures were more than three- and twofold, respectively, and for Clemenules, in 2007, captures were similar and in 2008, twofold higher (fig. 2).

The total adult capture per ha in the whole study period was analysed. For all varieties, years and trap densities, significant differences were found between years ($F = 9.44$, $df = 2$, $P = 0.0062$). The highest adult captures were in 2006, followed by 2008. There was no interaction between trap densities and year ($F = 0.55$, $df = 4$, $P = 0.7039$). No significant differences between trap densities were found ($F = 1.01$, $df = 2$, $P = 0.\ 4012$), but as the interaction between variety and trap density was significant ($F = 17.72$, $df = 6$, $P = 0.0002$), data were analysed separately by varieties. For each variety, the number of captured adults per ha was similar in all the trap densities tested (Clemenules: $F = 3.72$, $df = 2$, $P = 0.1224$; Marisol: $F = 0.44$, $df = 2$, $P = 0.6721$; Loretina: $F = 16.56$, $df = 2$, $P = 0.0569$) (fig. 4). In average, for all years and trap density, the total adult captures in the period were 496 ± 108 in Clemenules, 2227 ± 223 in Marisol and 2767 ± 1041 in Loretina (fig. 4).

Attacked fruits at harvest

Analysing the data altogether, the percentage of attacked fruits depended on variety ($F = 110.63$, $df = 2$, $P < 0.0001$), on the year ($F = 5.13$, $df = 2$, $P = 0.013$) and on the location of the fruit in the grove ($F = 83.45$, $df = 1$, $P < 0.0001$). A significant interaction was found between variety and the location of the fruit in the grove ($F = 54.\ 09$, $df = 2$, $P < 0.\ 0001$), and between variety and trap density ($F = 3.59$, $df = 4$, $P = 0.\ 0179$). Nevertheless, the percentage of attacked fruits did not depend on trap density ($F = 0.97$, $df = 2$, $P = 0.3904$), and there was no interaction between variety and year ($F = 0.2$, $df = 3$, $P = 0.8944$) nor between year and trap density ($F = 0.65$, $df = 4$, $P = 0.6324$).

Overall, the variety most affected by medfly attack was Loretina, with a mean percentage of attacked fruits of 5.27 ± 1.14, followed by Marisol (1.50 ± 0.24), and the least affected variety was Clemenules (0.50 ± 0.16).

Table 2 Mean and standard error of total soluble solids/acidity rate (E/A index) of the three citrus varieties studied at harvest time. Clementine fruits are considered mature if E/A index exceeds 6.5 (Martínez-Jávega et al. 1995)

	2006	2007	2008
Clemenules (1st week of November)	10.40 ± 0.20	7.77 ± 0.19	10.49 ± 0.20
Marisol (1st of October)	7.02 ± 0.25	7.01 ± 0.12	7.52 ± 0.13
Loretina (2nd week of October)	8.13 ± 0.15	8.37 ± 0.25	8.77 ± 0.53

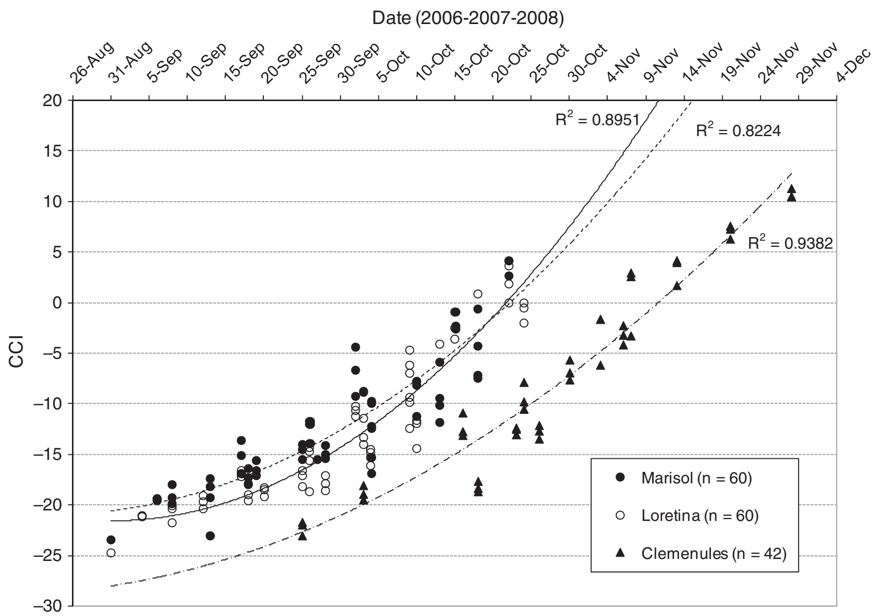

Fig. 1 Progress of rind colour (CCI) in three varieties of citrus clementines, expressed as CCI, the result of the 1000 *a/Lb* transformation from the *L* (0–100, black to white), *a* (yellow/blue) and *b* (red/green) Hunter laboratory parameters of the colour system were measured with a Minolta CR-400® chromameter.

Within each variety, the percentage of attacked fruits was different according to the year, being higher in 2006 compared with 2007 and 2008. This result coincides with a higher adult abundance in 2006 (fig. 2). The effect of fruit location within the grove (perimeter row vs. rest of the grove) was significant with regard to the percentage of attacked fruits, but because there was also an interaction between location and variety, each variety was analysed separately (fig. 5). In Loretina variety, for the entire grove, the location of the fruit was significant ($F = 46.96$, $df = 1$, $P < 0.0001$), so that the percentage of attacked fruits on the perimeter row was fivefold higher than on the rest (8.71 ± 0.82 and 1.83 ± 0.51, respectively). In Marisol and Clemenules varieties, these differences were also significant, although less pronounced. In Marisol variety, the percentage of attacked fruits on the perimeter row was twofold higher than on the rest of the grove ($F = 13.44$, $df = 1$, $P = 0.025$), being 2.16 ± 0.30 and 0.84 ± 0.19, respectively. In Clemenules variety, the percentage of attacked fruits on the perimeter row was twofold higher than on the rest of the grove ($F = 13.48$, $df = 1$, $P = 0.0025$), being 0.66 ± 0.25 and 0.34 ± 0.19, respectively.

To avoid data confounding owing to perimeter effect, the efficiency of the mass trapping method and its optimization according to the trap density per ha was estimated, excluding the perimeter row of the grove (fig. 5). No significant differences in any varieties were observed in the efficiency of the technique, according to the trap density (Loretina: $F = 1.43$, $df = 2$, $P = 0.4115$; Marisol: $F = 2.47$, $df = 2$, $P = 0.2052$; Clemenules: $F = 1.01$, $df = 2$, $P = 0.4413$). Analysing data from the perimeter row, significant differences were found only in Loretina variety (Loretina: $F = 27.57$, $df = 2$, $P = 0.035$; Marisol: $F = 1.02$, $df = 2$, $P = 0.4383$; Clemenules: $F = 0.46$, $df = 2$, $P = 0.6584$), although in this variety the percentage of attacked fruits in the perimeter row in the D50 density was similar to the other two, D75 and D100. Therefore, the percentage of attacked fruits was similar in all trap densities, both in the perimeter and in the rest of the grove (fig. 5).

Discussion

Citrus harvest often depends not only on the maturity parameters of the fruit, but also on trade requirements. Citrus fruits are not the most suitable host for *C. capitata* oviposition, mainly because of resistance mechanisms in the peel that affect their survival, fecundity and longevity (Bodenheimer 1951; Spitler et al. 1984; Papachristos and Papadopoulos 2009). However, at that time of the year, few hosts other than citrus are available for *C. capitata* oviposition. A colour index of CCI >−15 is considered to be the minimum value for artificial degreening in

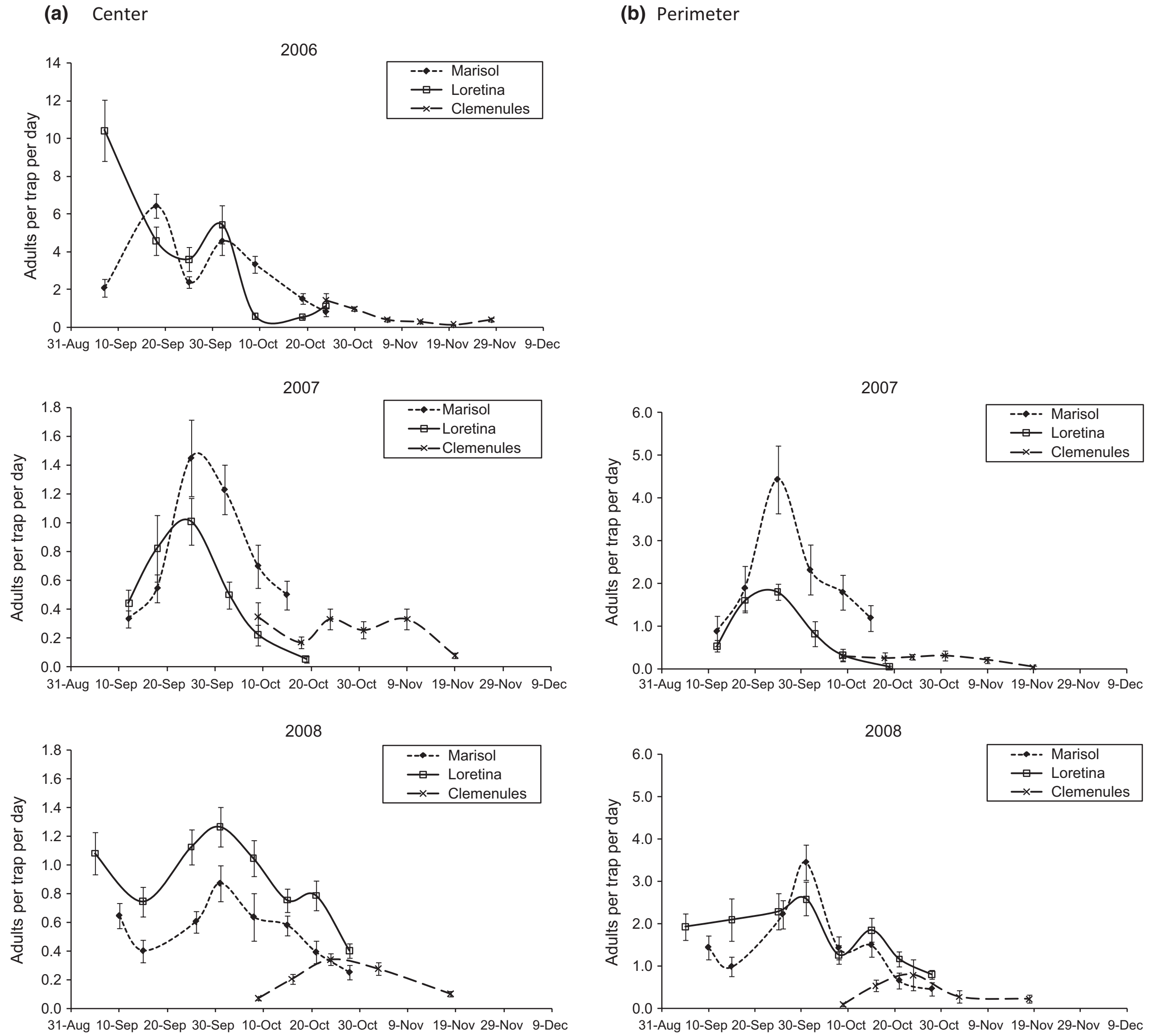

Fig. 2 Mean and standard error of the number of captured adults per trap and day in the D50 plots (50 traps per ha density) in the traps of the centre (a) and the perimeter (b) of the plot.

the citrus varieties tested here (Jiménez-Cuesta et al. 1981) and suitable for export market with reduced fruit fly infestations. In our experiments, this CCI value was achieved in mid-October for Clemenules variety and in the third week of September in the other two varieties.

The colour measure is an indicator of external ripening and, therefore, of how likely fruit are to be punctured by medfly, *C. capitata* that prefers to lay eggs in ripening or ripe fruits (Katsoyannos et al. 1998; Papadopoulos et al. 2001b). External ripening is not homogeneous over the whole fruit rind, and greenish and yellow patches coexist on the same fruit. When a fruit reaches an average colour index of −10, internal maturity has been achieved and at that moment several yellowish- and orange-coloured areas occur, increasing the contrast with the canopy. Fruit flies use colour and other visual characteristics such as shape, size, refractance intensity and contrast against background to detect fruits, mainly at a distance of less than a metre from the canopy (Drummond et al. 1984). This CCI value, −10, was reached, for the early-season varieties, when adult abundance was higher; thus, this moment is crucial for these varieties, and it occurred a few weeks before harvest. For the mid-season variety,

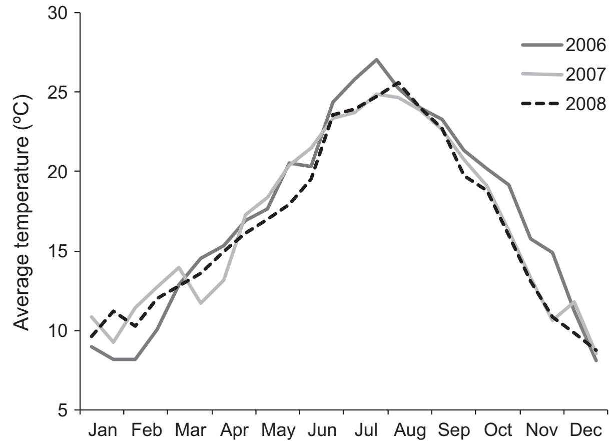

Fig. 3 Mean fortnight temperature from the three nearest meteorological stations of the study groves.

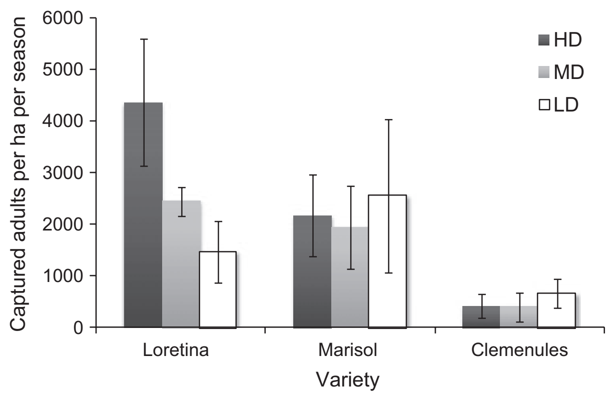

Fig. 4 Mean and standard error of captured adults per ha in the studied period in different trap densities: HD [high density: 100 traps per ha in early-season varieties (Marisol and Loretina) and 75 traps per ha in mid-season variety (Clemenules)], MD [medium density: 75 traps per ha in early-season varieties (Marisol and Loretina) and 50 traps per ha in mid-season variety (Clemenules)] and LD [low density: 50 traps per ha in early-season varieties (Marisol and Loretina) and 25 traps per ha in mid-season variety (Clemenules)].

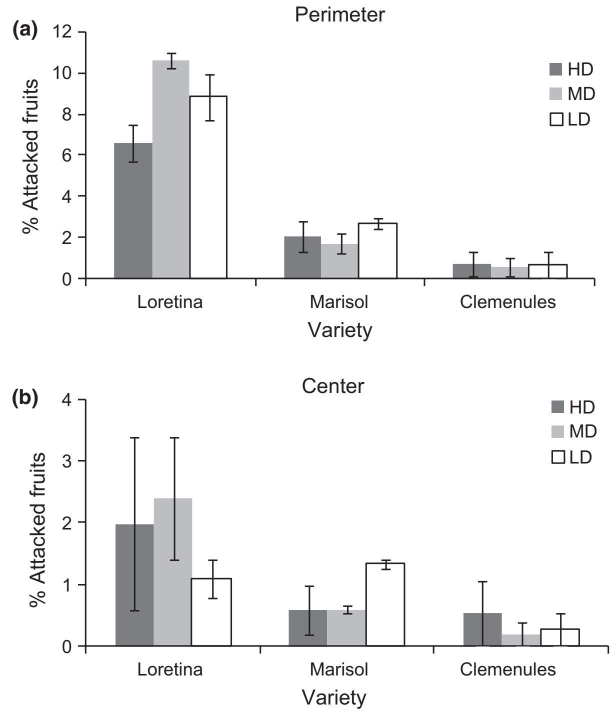

Fig. 5 Mean and standard error of percentage of *Ceratitis capitata* attacked fruits in the perimeter (a) and rest of the grove (b) in different trap densities: HD [high density: 100 traps per ha in early-season varieties (Marisol and Loretina) and 75 traps per ha in mid-season variety (Clemenules)], MD [medium density: 75 traps per ha in early-season varieties (Marisol and Loretina) and 50 traps per ha in mid-season variety (Clemenules)] and LD [low density: 50 traps per ha in early-season varieties (Marisol and Loretina) and 25 traps per ha in mid-season variety (Clemenules)].

CCI = −10 was reached later, at the end of October, when temperature and adult medfly abundance are lower.

Taking into account both efficacy and cost of trapping, we attempted to optimize the mass trapping density by comparing the efficacy of different trap densities (25, 50, 75 and 100 traps per ha) on several mandarin varieties. High-density trap grids have been used to detect *C. capitata* adults earlier (Papadopoulos et al. 2001a), but trials comparing different trap densities for mass trapping techniques are scarce. Target pest population density and isolation play a key role in the success of mass trapping, with particularly high success in isolated areas (El-Sayed et al. 2006). In general, captures were higher in the perimeter rows of the groves, suggesting a migration of medflies from outside the trapped area. The presence of maturing fruits, specially abandoned fig trees in mixed fruit gardens, has been reported as increasing *C. capitata* populations (Israely et al. 1997; Alemany et al. 2004; Campos et al. 2007). Adult population was 10-fold higher in 2006 than in 2007 and 2008. For all years, adult populations were always lower during the mid-season variety maturation, compared with the early-season varieties. According to the dynamics of *C. capitata* in this citrus-producing area, low temperatures in November cause dramatic population decreases from high populations in September and October (Martínez-Ferrer et al. 2006, 2007; Martínez-Ferrer et al. 2010). Modelling indicates that the efficiency of mass trapping increases as target population density decreases

(Barclay and Li 1991), making it an effective method for mid-season varieties, such as Clemenules. The early-season varieties reach maturity in late September and the beginning of October, when adult medfly populations are high and mass trapping is less effective. The overall adults captured per ha in the period were fivefold higher in the early-season varieties than in the mid-season variety, even when pesticides were applied to the former varieties during the trials. When analysing overall captures per ha, higher trap density did not result in increased captures, regardless of the year and the variety considered. But in early-season varieties, adult captures were higher than in mid-season one, according to the abundance of medflies foraging the trees.

A 50 trap per ha density has been widely accepted as appropriate for citrus orchards in Spain (Primo 2004; Ros et al. 2005; Navarro-Llopis et al. 2008). Miranda et al. (2001) distanced traps at least 15 m apart when testing different kind of traps and attractants, which meant hanging one trap per 225 m^2. Navarro-Llopis et al. (2008) resolved to hang the traps 20–25 m apart to avoid direct interaction between traps, which meant hanging one trap per 400–625 m^2. In our trials, densities D25, D50, D75 and D100 translated to one trap per 400, 200, 133 and 100 m^2, respectively. Our data suggest, for the Clemenules variety, that the 25 traps per ha were enough to capture adults flying within the grove and attract the foraging medflies, as low percentage of fruits were attacked. For the early-season varieties, 50 traps per ha captured as many adults as did 75 and 100 traps per ha, but not enough to diminish the adult medflies foraging in the grove under accepted levels.

The most common method to measure the efficacy of mass trapping is to monitor trap catches, providing an indirect measure of insect removal (Faccioli et al. 1993; Trematerra 1993). However, our purpose was to attract the highest amount of flies foraging the groves. Therefore, we selected the percentage of attacked fruits as the main indicator to test the efficacy of this technique.

Lure dispensers need to be long lasting to improve the efficacy of mass trapping (Navarro-Llopis et al. 2008). Adult medflies are present almost all year round in Spanish citrus groves (Martínez-Ferrer et al. 2006; Martínez-Ferrer et al. 2010), even when no susceptible citrus fruits are available to attack. Populations peak twice in a year, in summer and during early autumn, but citrus rind colour remains green until September. Consequently, we assume that hanging traps two months before harvesting is a sufficiently long period to protect Clementine fruit from medfly attack.

Several factors are involved in the attack of *C. capitata* to clementines. Temperature determines the adults flight: when the temperature declines during autumn, adults captures diminish dramatically. The rind colour is also a determinant issue, because if a certain colour value is not achieved, fruits are not susceptible to being attacked. These two combined factors clearly benefit the Clemenules variety. Thus, the percentage of attacked fruits was always lower in Clemenules compared with both early-season varieties, even without pesticide treatments. Nevertheless, these two factors alone do not explain that, in general, the Loretina variety suffered a higher attack than Marisol variety. Loretina fruits change their colour earlier in the stylar zone, whereas Marisol fruits show a more homogeneous ripening. Therefore, at certain moments, the average CCI of fruits was similar for the two varieties, but several areas of Loretina fruits showed a higher colouration than the rest, and therefore, even though the whole fruit would not be susceptible of being attacked, some areas would.

The percentage of attacked fruits at harvest was low (<1.5%) all years and densities in Clemenules variety. Taking into account that no chemical treatments were performed, and according to the results obtained, we can state that mass trapping is a valid standalone control method against *C. capitata* in varieties of Clementine that start maturing by November and that a density of 25 traps per ha is sufficient to ensure successful control of this pest. The attacked fruits on the early varieties were higher, coinciding with higher temperatures and adult populations, and pesticides were applied to minimize fruit infestation. But it is very interesting to note that if the perimeter row was not considered, and major chemical treatments are often applied only to this row, the percentage of attacked fruits was 1.83% in average for Loretina variety and 0.84% for Marisol variety. These percentages can be considered very low, if compared with non-treated or treated only with pesticides groves, and growers can accept them.

In Spain, the cost of mass trapping with a density of 50 traps per ha is similar to the cost of five chemical treatments (average number of treatments currently performed) (Navarro-Llopis et al. 2008). According to our results, the trap density in Clemenules variety can be reduced by 50%, thus saving half the cost of the mass trapping technique and avoiding chemical treatments. In early varieties, using 50 traps per ha, pesticide applications could be only required in the perimeter rows of the groves, increasing the cost respect to chemical treatments alone by 15%. Moreover, the benefits on non-target species and agrosystem are clear, achieving high efficacies. Our findings imply therefore that a control programme by mass trapping, with a minimized cost of using 25 traps per ha, can be implemented as a standalone method for mid-season Clementine varieties. For early-season varieties, depending on adult captures and temperatures, combining 50 traps per ha mass trapping with pesticide treatments to the perimeter row of the grove can still offer successful results.

Acknowledgements

Thanks to R. Monfort for helping us in the field work and to R. Colell, E. Fibla, J. Forés and J. R. Fabregat for permission to conduct field research on their groves. We also thank Probodelt, SEDQ and Opennatur for the supply of traps and attractants. Critical comments and suggestions from two anonymous reviewers greatly improved this paper. This research was funded by the Spanish Ministry of Education and Science, project RTA2006-00092-00-00.

References

Agunloye OJ, 1987. Trapping and chemical control of *Ceratitis capitata* (Wied) (Diptera, Tephritidae) on sweet orange (*Citrus sinensis*) in Nigeria. J. Hortic. Sci. 62, 269–271.

Alemany A, Miranda MA, Alonso R, Martín 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. Sanid. Veg. Plagas 30, 255–264.

Barclay HJ, Li C, 1991. Combining methods of pest control: minimizing cost during the control program. Theor. Popul. Biol. 40, 105–123.

Batllori JL, Vilajeliu M, Creixell A, Carbó M, Garcia N, Esteba G, Raset F, Vayreda F, Gine M, Curos D, Cornella J, 2005. Reduction of insecticide sprayings by using alternative methods in commercial apple orchards. Integrat. Fruit Prod. Fruit Crops, IOBC 28, 83–88.

Bodenheimer FS, 1951. Citrus entomology in the middle east. W. Junk, The Hague, The Netherlands.

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

Christenson LD, Foote RH, 1960. Biology of fruit flies. Annu. Rev. Entomol. 5, 171–192.

Chueca P 2007. Mecanización de métodos de control de *Ceratitis capitata* Wiedemann) en cítricos. Ph. D. Thesis. Departamento de Mecanización y Mecanización Agraria, Universitat Politècnica de Valencia, Spain.

Drummond E, Groden F, Prokopy R, 1984. Comparative efficacy and optimal positioning of traps for monitoring apple maggot flies (Diptera: Tephritidae). Environ. Entomol. 13, 232–235.

El-Sayed AM, Suckling DM, Wearing CH, Byers JA, 2006. Potential of mass trapping for long-term pest management and eradication of invasive species. J. Econ. Entomol. 99, 1550–1564.

Escudero-Colomar LA, Vilajeliu M, Batllori L, 2008. Seasonality in the occurrence of the Mediterranean fruit fly (*Ceratitis capitata* (Wied.)) in the north-east of Spain. J. Appl. Entomol. 132, 714–721.

Faccioli G, Pasqualini E, Baronio P, 1993. Optimal trap density in *Cossus cossus* (Lepidoptera: Cossidae) mass-trapping. J. Econ. Entomol. 86, 850–853.

Gazit Y, Rossler Y, Epsky ND, Heath RR, 1998. Trapping females of the Mediterranean fruit fly (Diptera: Tephritidae) in Israel: comparison of lures and trap type. J. Econ. Entomol. 91, 1355–1359.

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

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.

Jiménez-Cuesta M, Cuquerella J, Martínez-Jávega JM, 1981. Determination of a color index for Citrus fruit degreening. Proc. Int. Soc. Citriculture 2, 750–753.

Katsoyannos BI, Papadopoulos NT, 2004. Evaluation of synthetic female attractants against *Ceratitis capitata* (Diptera: Tephritidae) in sticky coated spheres and McPhail type traps. J. Econ. Entomol. 97, 21–26.

Katsoyannos BI, Kouloussis NA, Carey JR, 1998. Seasonal and annual occurrence of Mediterranean fruit flies (Diptera: Tephritidae) on Chios island, Greece: differences between two neighbouring citrus orchards. Ann. Entomol. Soc. Am. 91, 43–51.

Katsoyannos BI, Heat RR, Papadopoulus NT, Epsky ND, Hendrichs J, 1999. Field evaluation of Mediterranean fruit fly (Diptera: Tephritidae) female selective attractants for use in monitoring programs. J. Econ. Entomol. 92, 583–589.

Liquido NJ, Cunningham RT, Nakagawa S, 1990. Host plants of Mediterranean fruit-fly (Diptera, Tephritidae) on the island of Hawaii (1949–1985 Survey). J. Econ. Entomol. 83, 1863–1878.

Martínez-Ferrer MT, Campos JM, Fibla JM, 2006. Population dynamics of *Ceratitis capitata* on citrus in north-eastern Spain: influence of adjacent host fruit trees. IOBC/WPRS Bull. 29, 77–84.

Martínez-Ferrer MT, Alonso Muñoz A, Campos Rivela JM, Fibla Queralt JM, Garcia-Mar Fí, 2007. Dinámica poblacional de la mosca de la fruta *Ceratitis capitata* en tres zonas citrícolas mediterráneas. Levante Agrícola, Num 385, 92–98.

Martínez-Ferrer MT, Navarro C, Campos JM, Marzal C, Fibla JM, Bargues L, Garcia-Mar Fí, 2010. Seasonal and annual trends in field populations of Mediterranean fruit fly, *Ceratitis capitata*, in Mediterranean citrus groves: comparison of two geographic areas in eastern Spain. Span. J. Agric. Res. 8, 757–765.

Martínez-Jávega JM, Cuquerella J, Navarro P, 1995. Perspectiva actual de la tecnología postcosecha de frutos cítricos. Levante Agrícola 332, 220–225.

McQuate GT, Sylva CD, Jang EB, 2005. Mediterranean fruit fly (Dipt., Tephritidae) suppression in persimmon through bait sprays in adjacent coffee plantings. J. Appl. Entomol. 129, 110–117.

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

Navarro-Llopis V, Sanchis-Cabanes J, Ayala I, Castaña-Giner V, Primo-Yúfera E, 2004. Efficacy of lufenuron as chemosterilant against *Ceratitis capitata* in field trials. Pest Manag. Sci. 60, 914–920.

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.

Papachristos DP, Papadopoulos NT, 2009. Are citrus species favorable hosts for the Mediterranean fruit fly? A demographic perspective. Entomol. Exp. Appl. 132, 1–12.

Papadopoulos NT, Katsoyannos BI, Kouloussis NA, Hendrichs J, Carey J, Heath R, 2001a. Early detection and population monitoring of *Ceratitis capitata* (Diptera: Tephritidae) in a mixed-fruit orchard in Northern Greece. J. Econ. Entomol. 94, 971–978.

Papadopoulos NT, Katsoyannos BI, Carey JR, Kouloussis NA, 2001b. Seasonal and annual occurrence of the Mediterranean fruit fly (Diptera: Tephritidae) in northern Greece. Ann. Entomol. Soc. Am. 94, 41–50.

Primo E, 2004. Plan Valenciano de actuación contra la mosca de la fruta (*Ceratitis capitata* Wied.) campanya 2004. Agricultura: Revista agropecuaria 867, 790–793.

Ros JP, Wong E, Olivero J, Castillo E, 2002. Mejora de mosqueros atrayentes y sistemas de retención contra la mosca mediterránea de la fruta *Ceratitis capitata* Wied. Como hacer de la técnica del trampeo masivo una buena herramienta para controlar esta plaga. Bol. Sanid. Veg. Plagas. 28, 591–597.

Ros JP, Wong E, Olivero J, Rubio JR, Márquez AL, Castillo E, Blas P, 2005. Desarrollo de atrayentes y mosqueros para su integración en los programas de trampeo masivo contra la mosca de la fruta (''*Ceratitis capitata*'' Wied.) y la del olivo (''*Bactrocera oleae*'' Gmel). Bol. Sanid. Veg. Plagas. 31, 599–607.

SAS Institute Inc. SAS/STAT, 1998. User's guide, release 6.03 edition. SAS Institute Inc., Cary, NC 1028 pp.

Sokal RR, Rohlf FJ, 1981. Biometry: the principles and practice of statistics in biological research. W. H. Freeman, New York, 887p.

Spitler GH, Armstrong JW, Couey HM, 1984. Mediterranean fruit fly (Diptera: Tephritidae) host status of commercial lemon. J. Econ. Entomol. 77, 1441–1444.

Trematerra P, 1993. On the possibility of mass-trapping Synanthedon myopaeformis Bkh. (Lep., Sesiidae). J. Appl. Entomol. 115, 476–483.