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# From Chemicals to IPM Against the Mediterranean Fruit Fly *Ceratitis capitata* (Diptera, Tephritidae)

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## 1. Introduction

In Tunisia, the *Citrus* culture is important especially in the region of Cap-bon that is located in the North-eastern tip of Tunisia, and which is the main production area with about 15300 ha. In this region, the main source of income of approximately 25 000 rural households comes from *Citrus* farms, although most farmers have small orchards less than 5 ha (Zekri and Laajimi, 2000). The *Citrus* production reached during the campaign 2010/2011 an average of 354 000 T. The production of the oranges Maltaise that is the main variety, is about 50% of the total production. The other varieties most cultivated are the oranges Thomson, the clementines, the lemons, then the oranges Meski and Valencia late. Most of the production (80-90%) is sold in the local market, providing it in fresh fruits for up to 6 months per year. Some varieties and particularly the oranges Maltaise, are annually exported mainly to European Union with an average of about 23 000 T (Jemmazi, 2011 pers. com.).

However, the productivity of *Citrus* orchards is still below the desired level because the sub-sector is exposed to several constraints, such as the aging plantations, the climatic conditions, the availability of water and the problems of diseases and pests. Among these, the Mediterranean fruit fly is the most important pest, as *Citrus* leafminer, aphids, scales, mites and thrips recently (Jerraya, 2003; Trabelsi and Boulahia Kheder, 2010).

## 2. Current situation of the control of the medfly

The mediterranean fruit fly *Ceratitis capitata* is a harmful pest of many summer fruits and *Citrus*. The control of this pest is mainly chemical by terrestrial or airlift ways. These treatments using particularly Malathion, concern an area of about 10 000 ha in the region of Cap-bon. The treatments are made by the national company "SONAPROV" specialized in treatments, following the instructions of the Ministry of Agriculture. When the medfly populations tend upwards and their level reached the thresholds of 2-3 medflies/trap/day, the treatments were made. Thus, the treatments begin from September and are repeated until November totalizing an average of 6 passages. The farmers also made several chemical treatments on *Citrus*, up to 10 times, with very toxic Organophosphates, especially Malathion + Lysatex (food attractant) and Dimethoate. The biological products such as

Spinosad, which is homologated in Tunisia against the medfly, isn't frequently used because the farmers don't master its technique of application and consider it as not very effective.

On the other hand, there is an effort to develop biological control in *Citrus* orchards, especially against the *Citrus* leafminer for which the parasitoid *Semiolachar petiolatus* (Hymenoptera: Eulophidae) was imported, mass-reared and released in the orchards. The ladybugs *Novius cardinalis* and *Cryptolaemus montrouzieri* (Coleoptera: Coccinellidae) are also reared and released against the Australian mealybug *Icerya purchasi* (Hemiptera: Margarodidae).

Because of all the inconveniences of Organophosphates products on the environment, human health, auxiliaries, and resistance recently reported in Spain (Magana and al., 2008), an effort has been deployed during these last years to reduce their use and to find alternative methods to control the medfly. Among these, the mass-trapping technique used in many countries such as Spain and Greece (Miranda and al., 2001; Ros and al., 2002), was tried from 2006 in Tunisia.

### 3. Use of mass-trapping against the medfly

#### 3.1 First experience: On summer fruits

With the aim of substituting the chemical applications by alternative methods without side effects, the mass trapping was first tried on summer fruits in the region of Raf Raf (North-East of Tunisia). This region is very favorable to the medfly multiplication because of its proximity to the sea and the presence of summer fruits with overlapping maturities (medlar, apricots, peaches, pears, figs etc). The idea was: if mass-trapping succeeds to control medfly in this area, it can be transposed to other cultures and regions. The principle of mass-trapping is to capture the maximum of flies in a region by means of traps baited by food attractants. The attractants commonly used were hydrolysates of proteins, as females of medfly and especially the immature, are attracted by such component to mature their eggs (Placido-Silva and al., 2005; Quilici and al., 2004). For this first experience the attractant used was the Diammonium Phosphate (DAP) well known as a fertilizer by the farmers. This product was used at a concentration of 30 g/l and was renewed each week. The traps manufactured in Tunisia, were of the type Mac Phail but entirely transparent (Fig.1). They were installed from May 17<sup>th</sup> until December 12<sup>th</sup> 2006 at a density of 40 traps/ ha in an area of approximately 2 ha composed by family orchards.

The captures were monitored by sampling 36 traps whose contents were analyzed to separate non target insects from the medflies whose were counted each week.

The total number of medflies captured reached 90 000 during all the period. The density of medflies was the most important in August with an average of 330 medflies/trap/week (Fig. 2). At the end of this month, the captures reached a maximum of 1400 medflies/trap/week, which indicates a notable catch capacity of traps baited by DAP. Moreover, the percentage of medflies females captured was approximately 70%.

On the other hand, we noticed through this first experience that high proportions of non target insects were captured. Much more, the auxiliaries such lacewings (Nevroptera: Chrysopidae) and hoverflies (Diptera: Syrphidae), were rather numerous. Indeed the numbers of these insects captured during May until November, were respectively 35 and 804 that's equivalent to 1,5 and 33,5 individuals/trap/week.



Fig. 1. Food trap manufactured in Tunisia used for the mass-trapping of the medfly.

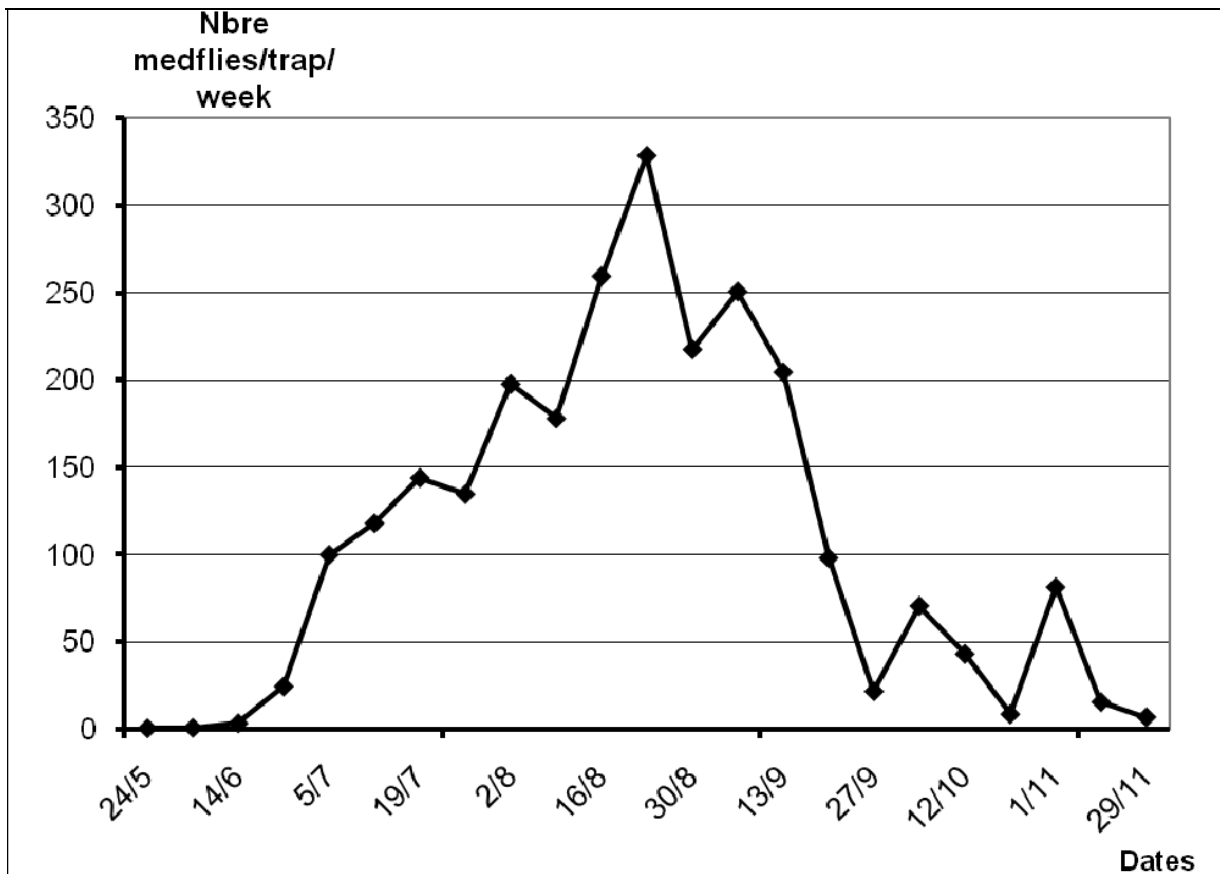


Fig. 2. Evolution of captures of medfly on summer fruits in the region of Raf Raf.

Regarding the mass-trapping effect on fruits, a survey conducted targeting the farmers (without statistical data), showed that this technique allowed a reduction of damages on figs, peaches and pears of approximately 30% compared to the previous years.

Although the disadvantage that the DAP must be renewed each week and attracts many non target insects, we considered that the results obtained with this attractant were promising; that's why we took again the essays on *Citrus* (Boulahia Kheder and Jerraya, 2010).

### 3.2 Next step: On citrus fruits

We chose for this second essay several orchards of clementines Cassar and oranges Thomson extending on a surface of 15 ha in the region of Takelsa in Cap-bon. For this essay the traps used were plastic Mac Phail traps baited with DAP. These traps were considered by Gazit and al., (1998), the best to capture females of *C. capitata* with food-based synthetic attractants. The traps were installed with a density of 40 traps/ha, on the 2<sup>sd</sup> of October 2006 until the 10<sup>th</sup> of January 2007. They were hung on the southeast side of the tree canopy, at 1,5-2 m above the ground.

In the middle of the "block" a plot of 1 ha containing 40 traps was considered as a sample. The traps were checked and their contents (medflies and non target insects) were counted and recorded every week.

The effectiveness of mass-trapping on the fruits was estimated by monitoring the punctures rate of clementines and oranges on 5 trees per species, 20 fruits per each tree. The fruits were marked when they were still healthy on October 17<sup>th</sup> and were monitored until the harvest to estimate the final punctures rate. At the harvest, the damages in the plot protected by mass-trapping were compared to those obtained in a control plot (without any treatments) and to those of an orchard treated according to a predetermined schedule, located few kms from experimental orchard.

The monitoring of the captures shows that the medfly has done 3 generations from October 9<sup>th</sup> to January 10<sup>th</sup>, the first one in late October and the others in early and late December. The most important one was the second, with a peak of 28 medflies/trap/week, coinciding with the maturity of clementines and oranges Thomson (Fig. 3).

Regarding the impact on fruits, on clementines the punctures started at late November and reached 7% at the harvest (Fig. 3). This percentage is comparable to that obtained in an orchard received 5 chemical treatments against the medfly (8,5%) and is significantly different from the control plot with 30% of damage.

As for oranges Thomson, at mid-December their puncture rate was 20% (Fig. 3), while in the treated orchard it was 1%. In the control, it reached about 33%. Further observations showed that oranges are attacked even when they are ripe; the puncture rate with mass-trapping reached 35% at early January (Fig. 3). This behavior was probably favored by the fact that when the clementines were harvested at early December, the only host available was the oranges Thomson. This phenomenon was described by Segura et al. (2002) as the return on the host explained by the strong trend of females of the medfly to lay their eggs in the host-plant in which they made their larval development.

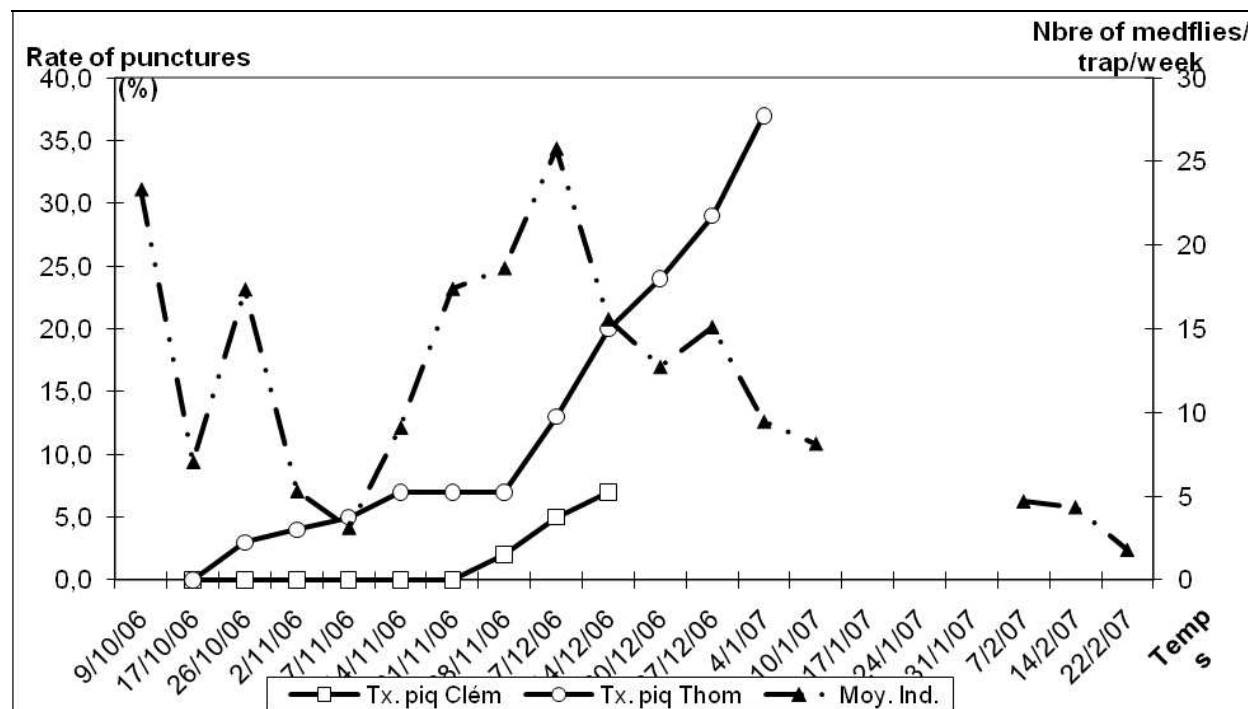


Fig. 3. Impact of mass-trapping on the evolution of catches and medfly damage on oranges Thomson and clementines in an orchard of the region of Takelsa.

In summary we can say that the mass-trapping could protect the clementines as effectively as chemical treatments, but it was insufficient for oranges Thomson whose receptive period is very long. The result obtained for clementines is close to that of Tison and al. (2003) and could be improved by an early installation of traps, before the ripening of fruits.

Comments on the selectivity of traps to auxiliaries have shown that the Mac Phail traps were more selective than transparent one, even when they are baited with the DAP, since the captures of lacewings and hoverflies were low with respectively 19 and 10 captured during 19 weeks with an average of 1 and 0,5 per week.

At the end of the second experiment we concluded that mass-trapping using DAP was able to protect adequately the clementines; but for oranges Thomson the level of medflies should be lowered further either by completing the mass-trapping by cultural practices or reasoned chemical treatments or by increasing the density of traps/ha (Boulahia Kheder and Jerraya, 2010). However this attractant has several disadvantages: low selectivity to auxiliaries particularly to the hoverflies, short-acting (7 days) and manipulation not practical. For further essays we added the first alternative in order not to increase the cost of trapping.

The following autumn, another trial was conducted in the same orchards in Takelsa region, but by installing the traps much more earlier and by using the synthetic food-based attractants Trimethylamine (TMA), Ammonium acetate (AA) and Putrescine (P) instead of DAP. These substances were the more appropriate for mass-trapping of the medfly (Miranda and al., 2001; Heath and al., 2004). These attractants formulated in separate patches, are known to be very female *C. capitata* selective, and to have a long duration of action (about 8 weeks). The traps used were plastic Mac Phail traps. They were hung at the same

conditions: 1,5-2m on the south side, and clearly visible in the canopy. Three plots were considered: the first one (I) was the control, in the second (II) which surface is 1 ha, 40 traps were baited by DAP and in the third (III) in the same way, 40 traps were baited by the 3 attractants with DDVP to compare the performances of the 2 types of attractants. The DDVP was placed on a cotton dental attached to the lid of trap and the cotton was moistened every 4 to 6 weeks. The attractants patches were changed every 8 weeks. The traps were installed on June 28<sup>th</sup> 2007 in plot III and from October 2006 in plot II.

In plots II and III the contents of traps were checked weekly for analysis and counting. All arthropods captured were identified to assess the selectivity degree of traps and attractants. The identification of families of Diptera was made in collaboration with Dr Martinez (INRA Montpellier).

The impact of mass-trapping on fruits was estimated by monitoring changes of puncture rate of 2 clementine and 2 orange trees per plot. On each tree, 100 fruits (25/orientation) were marked when they were still free of damage and followed from October 25<sup>th</sup> each week to detect punctures until the harvest ie November 28<sup>th</sup> and end of December respectively for clementines and oranges.

While during the previous trial conducted from October to December 2006, the medfly has developed 3 overlapping generations, it has developed 2 clearly individualized generations in the same period in 2007. Indeed the first one occurred in early October and the second in December (Fig. 4). The comparison of fluctuations and population number of medflies during the fall in 2006 and 2007 that are respectively relatively warm and dry, cool and rainy, suggests that the medfly is much more influenced by the availability of host plant, than by the annual variation of temperature, these whatever their seasonal fluctuations allow the development of the medfly (Boulahia Kheder and al., 2008).

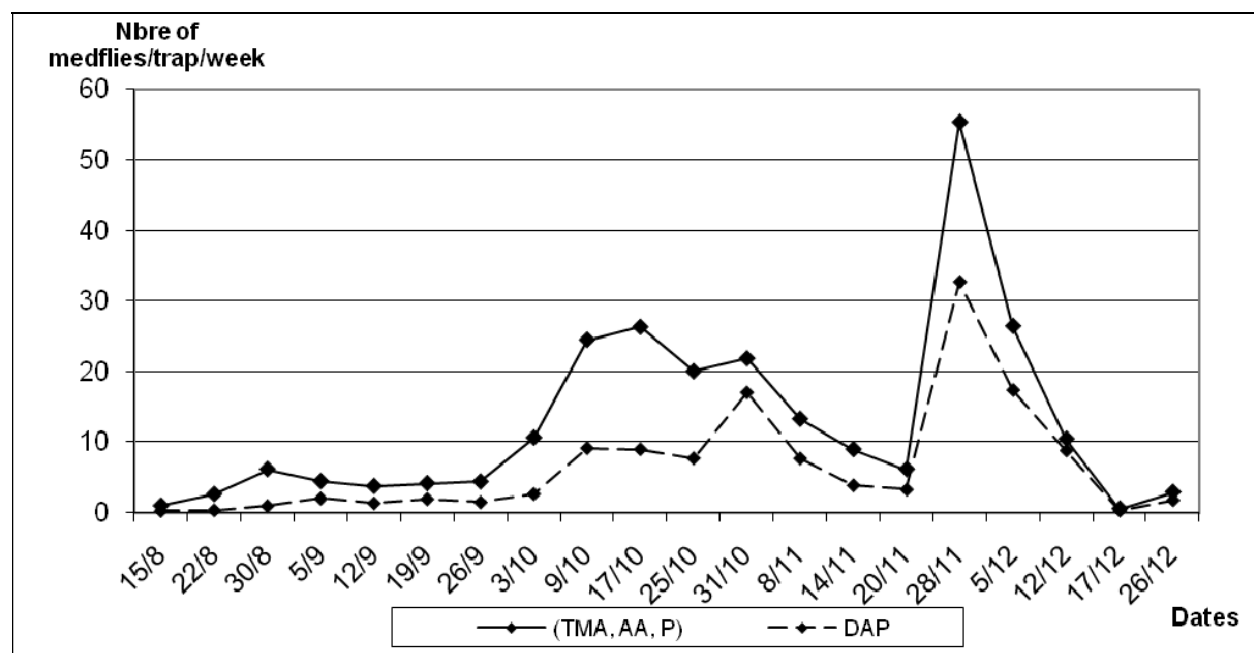


Fig. 4. Evolution of captures of medfly on oranges Thomson in an orchard of the region of Takelsa (August-December, 2007).

Regarding the protective effect of fruits by mass-trapping, it was very satisfying for clementines with no damaged fruits at the harvest for the 2 attractants, while the percentage of punctured fruits in control was about 5%.

By cons, on oranges Thomson although the mass-trapping protected the fruits comparing to control where the damage reached about 60%, the rate of punctured fruits was rather high with respectively 28 and 35% for the (TMA, AA, P) and DAP (Fig. 5). So, the 3 attractants are more efficient than DAP. This product has captured 2-3 times less flies than (TMA, AA, P) and the proportion of females was 70 and 90% respectively for DAP and (TMA, AA, P).

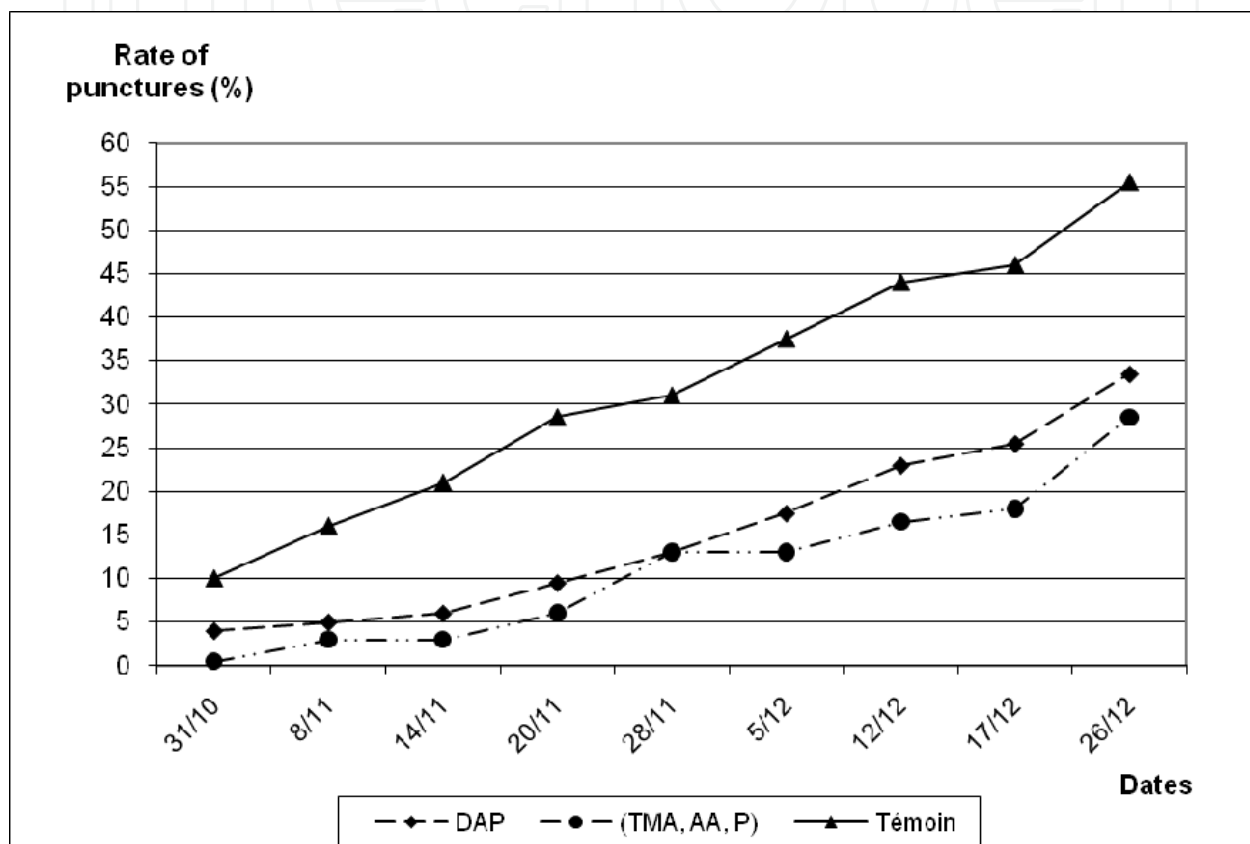


Fig. 5. Evolution of damage of medfly until the harvest with mass-trapping on the oranges Thomson (Takelsa, 2007).

Through this study we also tried to determine the selectivity of (TMA, AA, P) comparing to DAP. The identification of arthropods captured by the 2 attractants showed that the Diptera were the most represented order with 17 and 18 families respectively for DAP and (TMA, AA, P) (Table 1). In these families there are some insects that are beneficials such as Tachinidae, Syrphidae but this qualitative study did not allow to determine precisely the selectivity of attractants (Boulahia Kheder and al., 2008). A subsequent study conducted on figs, showed that the 3 attractants were very selective towards non target insects as their captures didn't exceed 3% of total insects (Boulahia Kheder and al., 2011).

In conclusion of the 2 first years of trials we could say that mass-trapping provide a real alternative to control the medfly in *Citrus* orchards but its efficiency is variable and depends on the varieties. Indeed, for the oranges Thomson whose receptivity to medfly is very long



(from early October to January) the mass-trapping alone can't protect them sufficiently and needs to be completed by other measures. Similar result was obtained by Médiouni and al. (2010) on Washington Navel oranges with 25-32% of damaged fruits at the harvest. That's why the insertion of the mass-trapping in IPM program constituted the next step of the work.

Fauna collected	Attractants	
	DAP	(TMA, AA, P)
<b>Insects</b> Diptera	Brachycera : Sarcophagidae, Chloropidae, Phoridae, Trixoscelicidae, Anthomyzidae, Calliphoridae, Sciomyzidae.  Nematocera :Scatopsidae, Mycetophilidae, Psychodidae.	Muscidae, Lauxaniidae, Lonchaeidae, Syrphidae, Odiniidae, Tachinidae, Ephydriidae,  Muscidae, Lauxaniidae, Lonchaeidae, Syrphidae, Calliphoridae, Pipunculidae, Stratiomyidae, Heleomyzidae, Therevidae. Nematocera : Scatopsidae, Bibionidae.
Coleoptera	Coccinellidae (1 specie) Staphylinidae	Coccinellidae (4 species) Staphylinidae
Hymenoptera	Especially wasps Vespidae and others Formicidae, rare parasitoids : Braconidae, Ichneumonidae	Vespidae and others Formicidae Braconidae Chalcidoïdae
Hemiptera	Leafhoppers, bugs	Leafhoppers, bugs, aphids
Nevroptera	Chrysopidae Hemerobidae	Chrysopidae Hemerobidae
Thysanoptera	Aeolothripidae	Aeolothripidae
Orthoptera	Ensifera	Ensifera
<b>Spiders</b>	Several species	Several species

Table 1. Insects and spiders captured by Mc Phail traps baited with 2 types of attractants (Takelsa, Sept.-Nov., 2007).

#### 4. IPM based on mass-trapping against the medfly

Several measures were tried between 2008 and 2010 to increase the effectiveness of mass-trapping such as the cultural practices, the chemosterilization, the applications of gibberillic acid, and chemical treatments if necessary with spinosad or other products.

To improve the performance of mass-trapping we have tried to use traps with better capacities of captures than the Mac Phail traps. So we compared these one to Moskisan, an improved version of Mac Phail: these traps have 4 inlets instead of one in Mac Phail traps. The attractants used were a new formulation of the 3 synthetic food attractants ammonium acetate (AA) (29,8%), trimethylamine (TMA) (12,4%) and putrescine (P) (0,2%) formulated in a unique patch (Unipack®). These lures have an improved duration of action that is of 4 months.

To compare Moskisan and Mac phail traps, a trial was conducted on figs from July 1<sup>st</sup> to August 12<sup>th</sup> 2009 in the region of Sidi-Thabet to compare their capacities of capture to medfly. The results obtained showed that in average the Moskisan traps captured significantly more medfly than Mac Phail ones (Table 2). Moreover, the details of captures per date shows that the number of medflies caught varies according to the population level. Indeed when this is very high, the Moskisan traps are more efficiency than Mac Phail, but when the level is lower the catching capacities of the two traps are similar (Figure 6).

These results allowed us to conclude that Moskisan traps are more efficient than Mac Phail for mass-trapping use and to choose these traps for the next experiments (Boulahia Kheder and al., 2011).

Traps	Number of meflies/trap/day
MacPhail	2.41 b*
Moskisan	4.74 a

\*The means followed by different letters differ significantly.

Table 2. Average number of medflies captured by Moskisan and Mac Phail traps from July 1<sup>st</sup> to August 12<sup>th</sup> 2009.

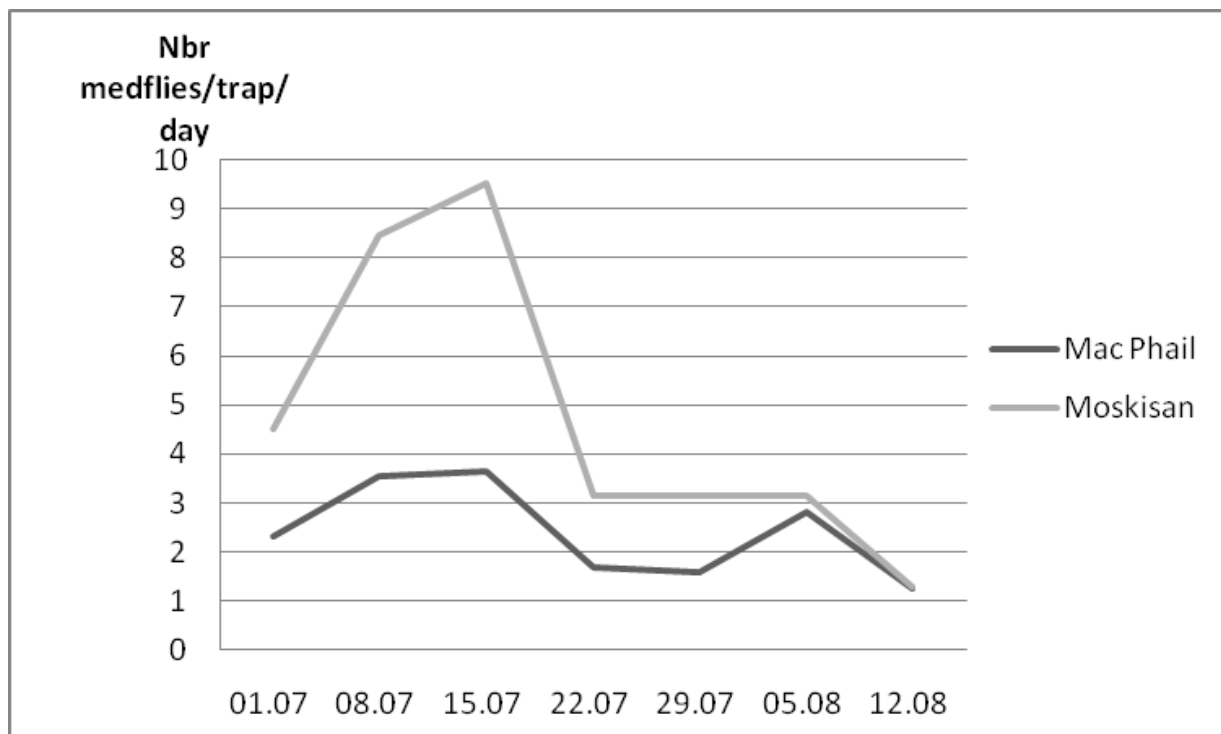


Fig. 6. Evolution of captured medflies in mass-trapping conditions according to traps baited with (AA, TMA, P).

The first combination tried was on oranges Valencia Late that's a variety also susceptible to medfly. It was the mass-trapping associated to cultural practices and to one insecticide application. This was made with deltamethrine at late February to maintain the medfly population at a low level. Cultural practices consisted of the collect of the dropped fruits each week. Mass-trapping used Moskisan traps baited with (AA, TMA, P) at a density of 40 traps/ha. The traps were installed from late January when the fruits were at early ripening. The plot conducted with this IPM program was compared to another conducted by mass-trapping alone. The effectiveness on production was evaluated by the weekly check for punctures of 200 fruits chosen randomly from 20 trees.

The application of IPM, combining mass-trapping, one chemical spraying and farming practices against the medfly, allowed a protection of harvest twice better than mass-trapping alone with a rate of punctured fruits of about 15% (Fig. 7). And we think that farming method rather than the deltamethrine spray, was the key factor in increasing the efficiency of the mass-trapping because on the totality of dropped fruits, about 52% were damaged by *C. capitata* (Table 3).

So this measure must be included in an IPM program against *C. capitata* and since, it was made in all programs. Fruit protection could also be improved by an earlier installation of the traps and by a chemical treatment rather at the end of March to prevent the medfly's populations increase (Trabelsi and Boulahia Kheder, 2011).

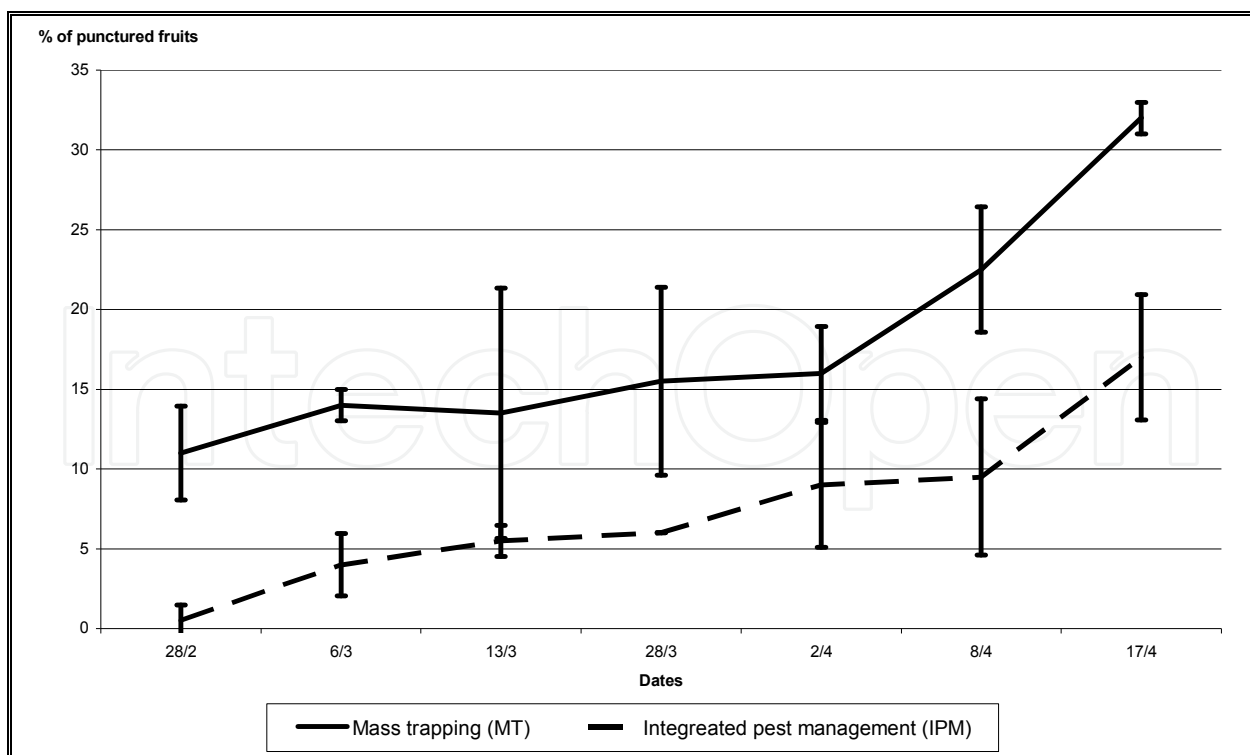


Fig. 7. Evolution of puncture rates on oranges Valencia late with mass-trapping and IPM.

Dates	Total number of dropped fruits	Damaged fruits		Healthy fruits	
		Nbre	%	Nbre	%
20/02	277	144	51,98	133	48,01
28/02	124	62	50	62	50
06/03	293	79	26,96	214	73,03
13/03	102	75	73,52	27	26,47
19/03	50	32	64	18	36
28/03	109	77	70,64	32	29,35
02/04	34	30	88,23	4	11,76
08/04	52	39	75	13	25
17/04	61	36	59,01	25	40,98
Total	1102	574	52,08	528	47,91

Table 3. Proportion of fruits damaged by the medfly versus the total of dropped fruits.

The second program applied was the combination of mass-trapping, cultural practices, chemosterilization and 2 chemical treatments using Organophosphates products when the medfly population exceeds the threshold. The chemosterilization was used by several authors and was not sufficient to allow a good protection of *Citrus* fruits and must be applied several years successively (Bachrouch at al., 2008; Navarro-Llopis and al., 2004, 2008). The idea was to combine the mass-trapping and the chemosterilization to improve their efficiency.

The orchard chosen for this trial was the same that for the previous work, located in the region of Takelsa. The trial began very early to ensure an efficiency maximum, from September 8<sup>th</sup> 2009 when the oranges Thomson were still dark green and small size (5-6 cm in diameter) and observations were made until January 6<sup>th</sup> 2010. The trial was made in an area of about 2 ha. The chemosterilant traps (Adress ®) placed at a density of 24 traps/ha, were baited by Trimedlure, Ammonium acetate, Trimethylamine and Putrescine and contained the Lufenuron gel sterilizing the females and males of *C. capitata*. The mass-trapping used always the same traps and attractants, but half of the traps contained a disk insecticide of cypermethrine (killdisc) and the other was filled by water. The aim was to compare the efficiency of dry traps and those with water that are less expensive, to make available for the farmers the less costly system; although it is known that water traps have the disadvantage to capture more non target species including beneficial insects (Miranda and al., 2001). Twenty chemosterilant traps were placed in the center of the plot and 48 traps for mass-trapping around the perimeter. The mass-trapping was reinforced at the periphery of the plot as a barrier to prevent the intrusion of medflies as recommended by Cohen and Yuval (2000). So our hypothesis was that the chemosterilant traps should sterilize the few of medflies that succeed to penetrate in the center of the plot, leading to low damage on fruits.

The impact of control methods (mass-trapping and chemosterilization) on the harvest was assessed by the rate of punctured and dropped fruits. Five trees per treatment and in a control plot were considered in which 80 fruits were marked from October 14<sup>th</sup> and checked each 2 weeks for punctures or drop. At the harvest the number of fruits checked per treatment was increased to 800. In addition a sample of 30 punctured fruits was collected 3 times, on late November then on early and late December to compare the evolution of eggs laid in fruits belonging to mass-trapping, chemosterilization and control.

The weekly monitoring of medflies caught in traps placed in all the experimental plot, shows that the captures were the lowest in the center of the plot where the chemosterilization was applied but with no significant difference with mass-trapping.

On the production the result was similar as the lowest damage was obtained on fruits from trees treated by chemosterilization: 14,6% versus 25%, 28 and 45% respectively in mass-trapping with water, with killdisc and control (Fig. 8).

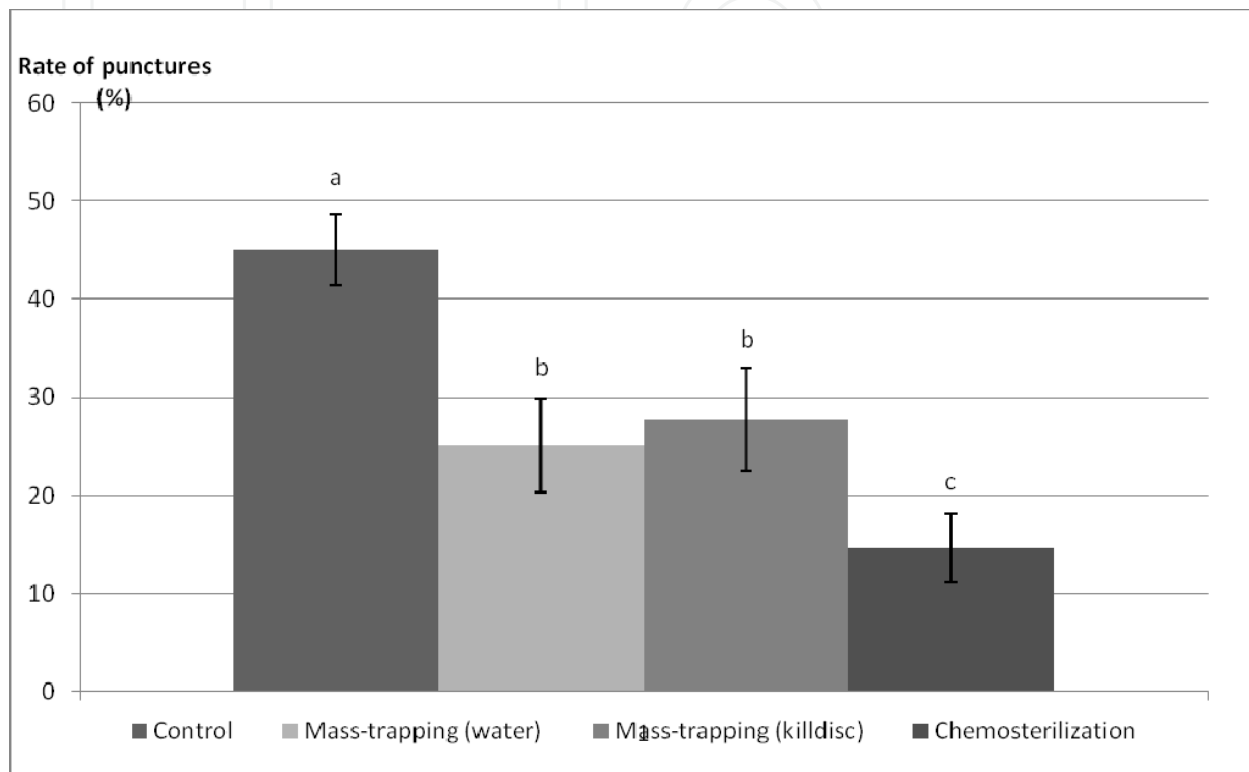


Fig. 8. Estimation of the medfly damage on oranges Thomson at the harvest with IPM based on mass-trapping and chemosterilization.

The rate of dropped fruits was very low (0,75%), compared to the other treatments (Table 4). Finally the examination of punctured fruits shows that the fruits collected from trees treated by chemosterilant traps, contained 10 to 40 larvae of medfly times lower than in mass-trapping and control respectively (Table 5). This result is consistent with that of Navarro-Llopis and al., (2004) and could be improved if this technique is maintained in the orchard for at least 4 consecutive years.

Plots	Number of fruits	%*
Control	25	6,25
Mass-trapping	8	2
Mass-trapping + killdisc	9	2,25
Chemosterilization	3	0,75

\*These percentages were calculated on 400 marked fruits/plot.

Table 4. Percentages of punctured and fallen fruits per plot (Takelsa, September 2009-January 2010).

Plots Dates	Control		Mass-trapping		Chemosterilization	
	Number of fruits	Number of pupae	Number of fruits	Number of pupae	Number of fruits	Number of pupae
November 25 <sup>th</sup>	30	26	30	6	30	0
December 9 <sup>th</sup>	30	15	30	3	30	0
December 23 <sup>rd</sup>	30	29	30	10	30	2
Total	90	70	90	19	90	2

Table 5. Number of pupae collected from punctured fruits per plot.

Based on the results obtained, we can conclude that the program combining mass-trapping, chemosterilization, cultural practices allowed a good protection of oranges Thomson at the harvest with about 15% of punctured fruits, that represents a gain of 5-10% versus to mass-trapping alone. Moreover, most of the punctures were sterile explaining the low rate of dropped fruits.

Another IPM program tested was mass-trapping, cultural practices and 2 applications of gibberellic acid. The applications of gibberellic acid on oranges when they had the size of a golf ball, by delaying the ripening period, allowed a good protection of them from the medfly in Brazil (Malavasi and al., 2004).

Inspired by this result, we have tried to apply it in combination with mass-trapping. So, always on oranges Thomson, mass-trapping was associated with farming practices, reasoned chemical control and 2 gibberellic acid applications in an IPM program.

The traps used for mass-trapping were always of the type Moskisan® with a density of 40/ha, baited by the 3 synthetic attractants Ammonium acetate, Trimethylamine and Putrescine (Unipack®). In addition to the application made usually by farmers in the spring to improve fruit set, 2 gibberellic acid applications were made in early august and late September on small size fruits (3 and 6 cm of diameter) in order to delay their colour-break, critical stage for the attack of medfly. The dose used was 1g of gibberellic acid/hl. Chemical control was reasoned according to the medfly population level. Farming practices consisted in regular collect of dropped fruits. This program was compared to mass-trapping with traps filled with water or containing killdisc and the chemical control with 3 applications of Organophosphates products. In all plots the fallen fruits were regularly collected except in the control one.

The efficiency of the IPM program based on mass-trapping and gibberellic acid applications was evaluated by the weekly monitoring of the medfly populations level and rate of punctured fruits until the harvest.

In the plot with IPM program, the medfly populations level was the lowest, but with no significant difference between the others modalities and significantly different compared to the control plot. Moreover, since there is no difference between the 2 types of mass-trapping we considered that using traps with water is the most economically advantageous technique.

Otherwise, this IPM program reduced significantly the damage on oranges Thomson with approximately 11 % of punctured fruits at harvest against 33 % in the control field (Fig. 9).

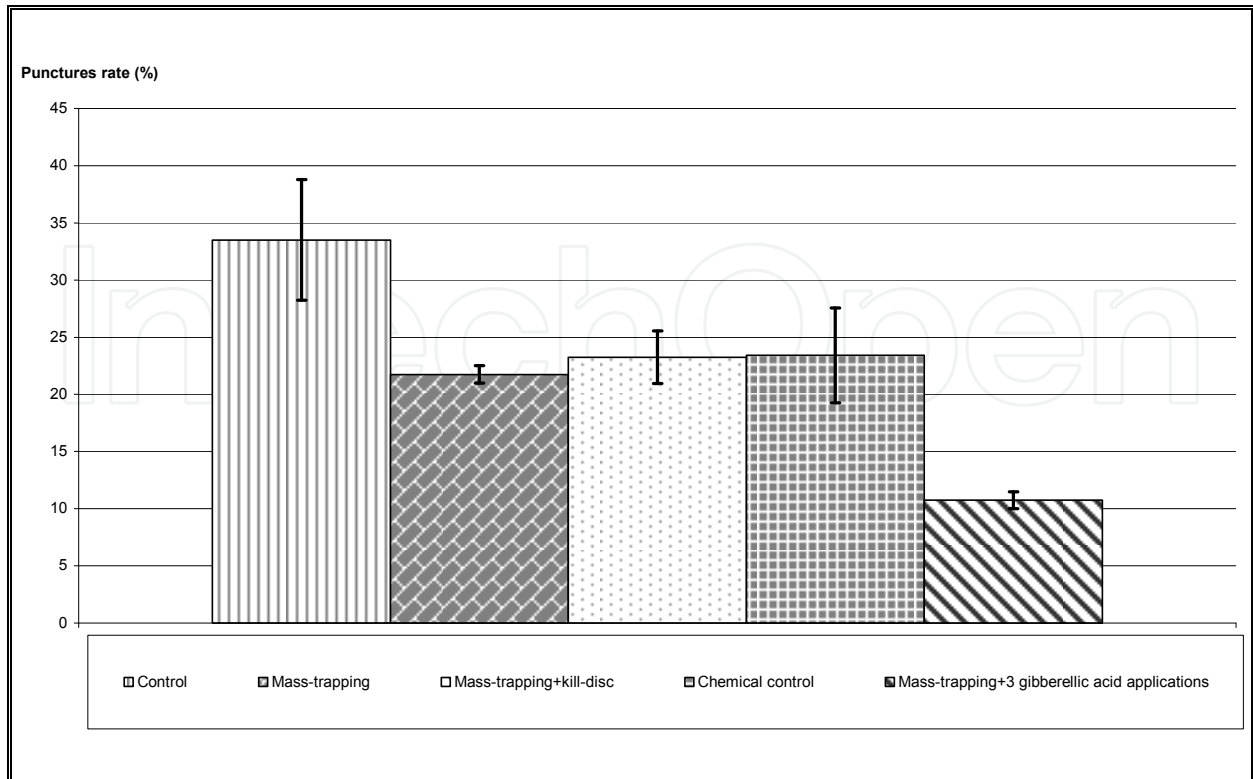


Fig. 9. Estimation of the medfly damage on oranges Thomson at the harvest with several IPM programs based on mass-trapping (Sidi Thabet, February 2010).

This program was significantly better than mass-trapping and chemical treatments in protecting fruits. The control of a sample of 400 fruits received gibberellic acid applications in the IPM plot, showed that on November 17<sup>th</sup> 60% of them were dark green while none of the fruits in the control was at this stage, but most of them were already ripe (Table 6) (Fig. 10). Thus, delaying the maturity of fruits at late December that's a cool period (average temperature < 9°C), the gibberellic acid allowed the fruits to escape the infestation of medfly because of the very low population level at this period. Indeed, from the beginning of the fruit ripening to the harvest, the punctured rate of fruits sprayed by gibberellic acid increased only about 6% against an increase of respectively 19, 21 and 32% in plots treated respectively by mass-trapping, chemical treatments and control.

Phenological stages Treatments	Dark green fruits		Light green fruits		Ripe fruits	
	Number	%	Number	%	Number	%
IPM	241	60,25 %	159	39,75%	0	0
Control	0	0	43	10,75%	357	89,25%

\* These percentages were calculated on 400 randomly selected fruits/treatment.

Table 6. Fruits phenological stages in the IPM (mass-trapping + 2 gibberellic acid applications + farming practices + reasoned chemical control) and control plots 2 months before harvest (Sidi Thabet, November 17<sup>th</sup> 2009).



Fig. 10. Effect of gibberellic acid applications on oranges Thomson (a: untreated oranges; b: oranges treated 3 times by gibberellic acid) (Sidi Thabet, November 17<sup>th</sup>).

So we can conclude that IPM based on mass-trapping and 2 gibberellic acid sprays improve the resistance of oranges Thomson to medfly by delaying 3 weeks their ripening. This is a promising result as the gibberellic acid is a natural substance without risk for human. Moreover, this substance did not affect the technological characteristics of juice (Ben Amor, 2009). The question is whether this substance does not cause adverse effects on the future production of the tree.

In conclusion of these trials, we can say that when the mass-trapping is inserted in IPM programs, its efficiency to protect fruits until the harvest, increase significantly provided that the farmers participation are involved in the operation. This is very important because



the farmers must collect at least 2 times / week the fall fruits and must monitor the population level of medfly by traps to spray chemicals when the threshold is reached. So there is a need for training and supervision of the farmers to acquire the basics of IPM practices.

## 5. Prospects of extension of IPM in citrus orchards

Following these successful trials carried out on small areas, and the promising results obtained with IPM programs based on mass-trapping in protecting the oranges Thomson, until the harvest, the Tunisian Ministry of Agriculture decided to extend this alternative method to a larger surface. This project was conducted in the region of Takelsa in the Capbon (Tunisia) on about 300 ha of *Citrus*. The program applied has combined the mass-trapping to cultural practices and aerial sprays. All these operations, except the collect of fruits fall, were supported by the Ministry of Agriculture.

Moskisan traps were distributed to farmers depending on the size of their orchards. To begin trapping before the receptivity of fruits, the farmers installed the traps at a density of 40/ha around mid-August. The traps were baited by the 3 synthetic food attractants ammonium acetate (AA) (29,8%), trimethylamine (TMA) (12,4%) and putrescine (P) (0,2%) formulated in a unique patch (Biolure Unipack Suterra LLC U.S.A). These lures have a duration of action of 4 months. A killdisc of pyrethrine was added in each trap to make it easier for farmers.

The treatments were applied by aerial way using the bioinsecticide spinosad at the dose of 1 L/Ha mixed in 6 L of water. Four treatments were carried out (on August 19<sup>th</sup>, September 17<sup>th</sup>, October 7<sup>th</sup> and November 1<sup>st</sup>) following the instructions of the Ministry of Agriculture when the medfly populations tend upwards and when their level reached the thresholds of 2-3 medflies/trap/day. The treatments were carried out by means of helicopters of the SONAPROV by alternate bands of 20 meters. In some orchards inaccessible by aerial way, the farmers treated by Organophosphates such as malathion and dimethoate.

To evaluate this experiment, we considered 2 orchards, one received aerial treatments, and the other terrestrial applications, as samples.

The IPM program based on aerial treatments combined with mass-trapping was more effective to protect fruits, than that based on terrestrial treatments combined with mass-trapping. This result was confirmed by the data obtained at the harvest. Indeed, the final rate of punctured fruits obtained with aerial treatments was 2,05% on the 10<sup>th</sup> of March (24 punctured fruits over 1168 fruits observed). In the orchard with terrestrial applications, it was 8,51% (317 punctured fruits over 3341 fruits observed) on February 1<sup>st</sup> (Fig. 11).

So we can conclude that the mass-trapping supplemented by 4 aerial treatments with spinosad and the systematic collect of fallen fruits was very effective to protect the oranges Thomson against the medfly (Boulahia Kheder and al., 2011).

This result is so important that it allowed the adhesion of the farmers to mass-trapping and improve their “confidence” to the spinosad. Although homologated for several years in

Tunisia, this product is under used by the farmers against medfly because they consider it inefficient and costly.

Thus, with this first experiment where the mass-trapping was used at a relatively large scale, the surfaces treated against medfly by chemical products can be gradually reduced to the profit of the IPM programs based on mass-trapping.

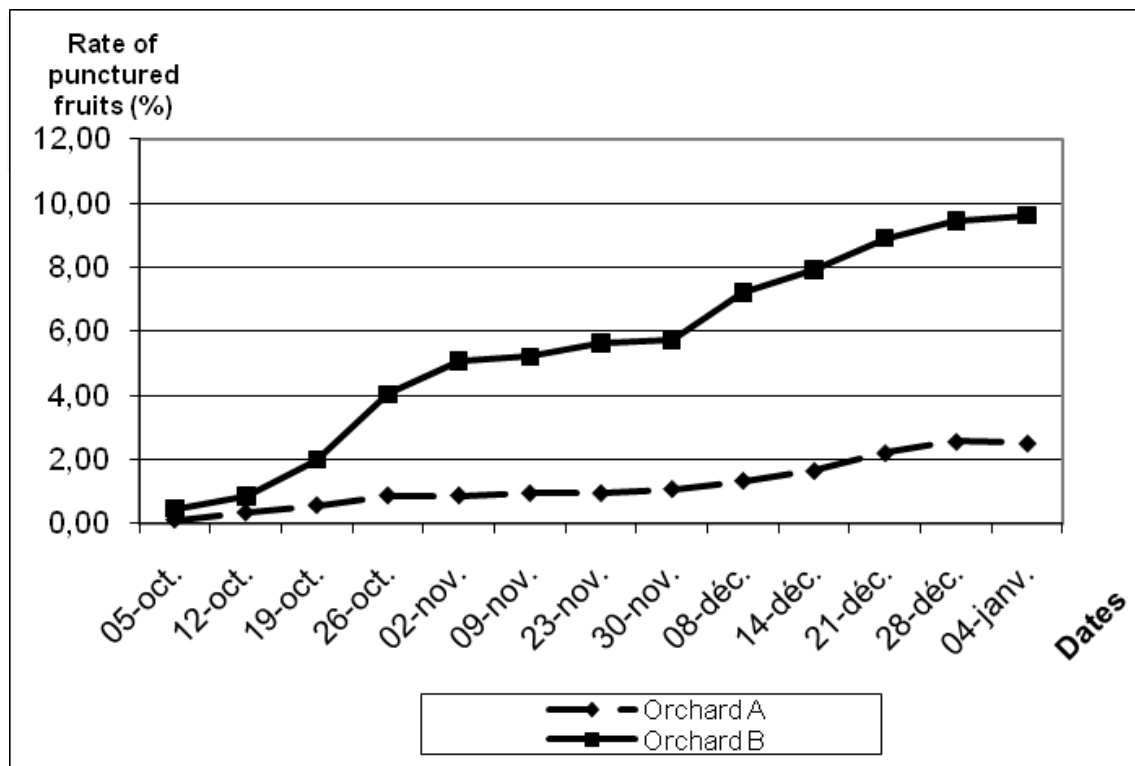


Fig. 11. Effect of the IPM programs applied on the production in 2 orchards: A (mass-trapping + aerial treatments + cultural practices) and B (mass-trapping + terrestrial treatments + cultural practices).

### 6. Conclusion

Several trials conducted during 5 years to promote the use of mass-trapping to replace the chemical sprays to control the medfly on *Citrus*, obtained good results when this technique was included in an IPM program. Supplemented by cultural practices, and other measures the mass-trapping protected the oranges Thomson and clementines until the harvest with a percentage of damage around 2-10%. This allowed the acceptance of this technique by the farmers and has resulted to an increase demand for traps.

The bases of IPM against the medfly in *Citrus* orchards are thus initiated; it remains to consolidate them by the training of farmers to involve them in the monitoring of population level of the medfly.

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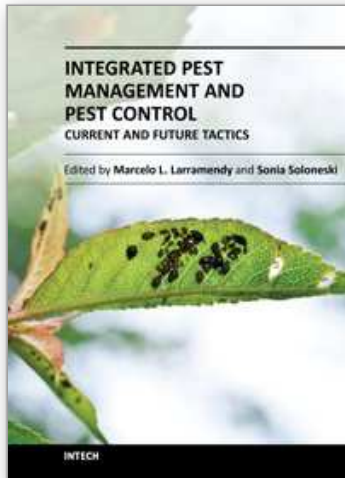
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