International Journal of Research in Agricultural Sciences
Volume 3, Issue 4, ISSN (Online): 2348 – 3997

Comparison of the Effect of Spinosad, Kaolin and Protein Bait Spray on *Ceratitis Capitata* (Diptera: Tephritidae) in Citrus Orchards in the Gharb (Morocco)

Smaili M.C.[1*], A. Bakri[2], F. Gaboune[3], R. Bouharroud[4] & A.Blenzar[5]
[1]:National Agricultural Research Institute, Kenitra, Morocco, [*]Email:csmaili@yahoo.fr; [2]:Insecte Contrôle, Marrakech, Morocco; [3]:National Agricultural Research Institute, Rabat Morocco; [4]:National Agricultural Research Institute, Agadir Morocco; [5]University of Moulay Ismail, Faculty of Sciences Meknes Morocco

***Abstract* – Phytosanitary practices based on the extensive use of insecticides in citrus groves to control the Mediterranean fruit fly *Ceratitis capitata* may cause the resurgence of resistant strains of this pest, the emergence of secondary pests by elimination of their natural enemies, and increase the growing public concerns over issues related to public health, environmental quality, and food safety. Therefore, there is an urgent need to develop an alternative and environmentally compatible method for *C.capitata* management. This study evaluated the efficacy of treatments using kaolin, spinosad bait or the protein bait application technique (BAT), and assess how these different treatments may be associated with improved control of *C.capitata* on several citrus varieties. Experiments were conducted in citrus orchards in the Gharb area (North-western part of Morocco): plots of Clementine (*Citrus reticulata*, var. Cadoux), sweet orange (*C.sinensis*, var. Hamlin; Washington Navel and Thomson). Success bait (spinosad + food attractant), kaolin suspension and protein bait application technique, based either on deltamethrin (dBAT) or malathion (mBAT) were applied on citrus plots against *C.capitata*. The effect of these treatments on fruit infestation by *C.capitata* was also assessed. At harvest, a sample of 1000 fruits was picked randomly from each plot and examined to assess the infestation percentage. There were fewer medfly captured and lower associated fruit infestation in the plots treated with the kaolin compared to those treated with BAT or spinosad. Kaolin used at a low concentration (1.4%) showed a similar level of infestation to spinosad. Based on these field results, it appears that sweet orange (*C.sinensis*, var. Hamlin) is the most tolerant to *C.capitata* infestation. The feasibility of combining resistant citrus varieties with these alternative methods of population management is discussed; and will be considered in the development of an integrated pest management strategy against *C. capitata* in citrus groves in Morocco.**

***Keywords* – Morocco, Citrus, Varieties, Medfly, Integrated Pest Management.**

I. INTRODUCTION

In Morocco, citriculture is one of the major economic sectors with citrus plantings approximating 114 000 ha, and with a production estimated as 2.2 million tons [26]. In addition, citrus exports generate an important source of foreign currency approximately €0.27 billion per year [25]. It also contributes significantly to employment in orchards and in the packing, and processing segments and many other related industries. In Morocco citrus production yields are approximately 16 tons/ha, which is low compared to other countries. Several factors, particularly insect pests, contribute to limiting the production and affect fruit quality [12], [1],[2],[3],[6]. In Morocco, the Mediterranean fruit fly, *Ceratitis capitata* Wiedemann (Diptera: Tephritidae) (medfly) is a key citrus pest and annually requires several chemical treatments mainly for the early varieties [42],[4],[28]. In commercial Moroccan citrus groves, current medfly control is based essentially on several applications of synthetic pyrethroid or organophosphate insecticides, especially lambda-cyhalothrin, deltamethrin and malathion, mixed with hydrolyzed protein bait, and applied in a fruit fly bait application technique (BAT). However, the presence of chemical insecticides in the bait formulation limits its use in citrus orchards because of the side effects on natural enemies [14] and the environment, and the contribution to the development of resistance in the target insect [24]. Additional reasons for developing new approaches to control of *C.capitata* in Morocco include new restrictions on the chemical products used against *C.capitata*, the current trend of citrus growers to adopt good agricultural practices such as integrated pest management, increased awareness of the role of naturals enemies, and the impact of insecticide treatments on citrus fruit quality (insecticide residues) which hinders fruit exports. In this context, several new approaches have been tested elsewhere for *C.capitata* control such as the use of essential oils extracted from several plant [35], insect growth regulators [30],[23], baits with a chemosterilant (e.g. lufenuron) [33], and the sterile insect technique [16]. Mass trapping, is also an important method of controlling medfly population [27],[31]. In this context, there are significant differences in efficacy between different types of *C.capitata* traps and dispensers and the appropriate selection of the trap and dispenser will thus improve mass trapping of *C.capitata* in citrus groves [32],[31]. This study suggests that the use of Probodelt trap which caught significantly more flies than the others traps.

It has also been found that spinosad, contained in GF-120, is an effective natural insecticide against Tephritidae [50],[13] with a better environmental profile. During recent years, this natural insecticide was successfully used in controlling many tephritid pests [9],[46]. In reviews on particle film technology based on the mineral kaolin [15],[36]. The authors reported that the particle film allows the exchange of gases from the leaf during photosynthesis (transmits photosynthetically active radiation=PAR) and transpiration, while its reflective properties reduce heat stress and increase photosynthesis, fruit size and yield. Furthermore, kaolin is a white non-

porous, chemically inert, a natural non toxic mineral consisting of fine white particles of modified clay, suspended in water and applied as a so-called particle film [15],[36]. Kaolin has also been found to be very effective when applied to crops to deter insect damage by a variety of pests e.g. Lepidoptera [38],[22], Coleoptera [41],[5], aphids [18] and also phytophagous mites [22]. The beneficial effect of kaolin barriers for controlling pests was also reported against spring population of *Dysaphis plantaginea* Passerini (Hemiptera : Aphididae) [51] and *Thrips tabaci* Lindeman (Thysanoptera:Thripidae) [19]. Kaolin effectiveness was also reported to control others dipterous species such as *Bactrocera oleae* Gmelin (Diptera : Tephritidae) [39] and *Rhagoletis pomonella* (Diptera :Tephritidae) in apple [49]. Laboratory and field trials with fruits treated with the processed kaolin 'Surround WP' in nectarines, in apples and in persimmons indicated an almost complete protection of fruit infestations by *C.capitata* [29]. Kaolin residues on citrus fruit can be easily eliminated by natural processes in the field or by rinsing fruit with water in the industry process and can be removed from harvested commodities [36]. This work aimed to compare *C.capitata* control methods based on spinosad, kaolin and the two routine BAT mixtures applied on various citrus varieties under Moroccan conditions.

II. Materials and Methods

Field Descriptions

All fields trials were conducted in the Gharb area, located in one of the main irrigated citrus production zones in Morocco, with an average rainfall of 500 mm/year. Field trials were conducted in two citrus stations: At Kenitra, approximately 25 km inland, two citrus fields were selected, one was planted with Clementine var. Cadoux (*Citrus reticulata Blanco* cv Cadoux) and the second with Orange var. Hamlin (*C.sinensis* (L.) Osbeck cv Hamlin). The sites were approximately 100 m from each other. At Sidi Slimane, two separate field trials were conducted in an orchard located 60 km east of Kenitra. One field was planted with Navel var. Thomson (*C.sinensis* (L.) Osbeck cv Thomson) and the other with Navel var. Washington (*C.sinensis* (L.) Osbeck cv Washington).

Product Description

Kaolin

Kaolin is a inert white fine powder that is combined with a sticker-spreader in suspension. In the field experiments, the citrus trees were sprayed with kaolin (Kaolin formulated product, Agriman Firm, Casablanca, Morocco) applied by a conventional, 1500 L air blast sprayer, at a rate of approximately 2000 L/ha. Kaolin was used at 1.4% during the 2007 field trials and all trees in all rows were completely covered with the kaolin suspension. Based on the *C.capitata* trap captures and fruit punctures recorded, the first kaolin treatment started on October 3rd. At this time, color break of fruit occurred, *C.capitata* populations are generally very high and citrus fruits are very attractive.

Spinosad

Success® bait is a spinosad-based insecticide (spinosad 0.24g/l and food attractants 99.76 g/l (Dow AgroSciences/Promagri, Casablanca, Morocco), and was applied as bait spray (1L spinosad/60 L water/ha, recommended dose by firm) using a backpack sprayer with an adjustable nozzle producing droplets. An area of approximately 50 cm² on the southern lower part of the tree canopy was sprayed. The spinosad treatments were started in the same time like kaolin application.

BAT with Deltamethrin

The protein bait application technique using deltamethrin (dBAT) was applied by ground sprays of an area of approximately 100 cm² on the southern lower part of trees (not all trees). The mixture formulation included Decis® 25 EC (25 g/L of deltamethrin at a rate of 12.5ml/ 100 L of water; Bayer CropScience, Casablanca Morocco) mixed with protein hydrolysate (food attractant at a rate of 1L/100 L of water, Promagri, Casablanca Morocco) at an application rate approximately 60 L/ha. The dBAT mixture (Decis 25EC 0.7%; proteins hydrolysate 0.7%; water 98.6%) was applied using a conventional backpack sprayer with an adjustable nozzle. The fruit fly bait was applied in large droplets (e.g. 2-4 mm diameter). The dBAT treatments were started when 1.0% of 200 examined fruits were infested by *C.capitata* [43], [4].

BAT with Malathion

The protein bait using malathion (mBAT) was applied by ground treatment with a conventional 1500 L air blast sprayer. The mBAT formulation included Malathion® 50 EC (50% ma1athion, Promagri, Casablanca Morocco) at a rate of 200 ml/100 L; protein hydrolysate (food attractant at a rate of 1.5 L/100 L of water) and water with at a rate of approximately 1500 L/ha. The mBAT treatment was sprayed on the south side of the trees of the same one from every third row of the selected plots.. In Morocco, mBAT was sprayed from the end of August until harvest (December) according to the calendar schedule of treatments already established by citrus growers to control *C.capitata*.

Traps

Maghrebmed traps (White cylindrical plastic trap with two opening) baited with trimedlure (Agrospray Rabat, Morocco) and DDVP (0.5 g a.i. dimethyl 2,2-dichloroethenyl phosphate, per tablet, Agrospray Rabat, Morocco) were used to monitor *C.capitata* males. Traps (one trap per plot) were suspended on the southern part of the tree approximately 1.5 m from the ground. Traps were checked weekly from October until harvest and replaced after every two or three samplings. This period often coincides with high *C.capitata* populations and significant associated fruit infestation in the Gharb area.

Assessment of Citrus Fruit Infestation

Citrus fruit infested by *C.capitata* show at least one oviposition puncture with a characteristic yellowish coloring around the site (the 'sting'). The percentage of infested fruit was assessed in samples of 200 fruits (20 fruits x 10 replications) of orange color collected from each plot at regular intervals.

Field Trials

Comparison of the effect of kaolin 1.4% and malathion-based protein bait spray on the Clementine var. Cadoux (Kenitra).

The trial was conducted from 31/08/2007 until fruit harvest on 27/12/2007, in an orchard of Clementine var. Cadou at Kenitra, arranged in four plots. Two plots were treated with kaolin 1.4% every 7 days (Ck7) and 14 days (Ck14), the third plot was treated every 7 days with malathion-based protein bait spray (CmBAT), and the fourth plot was sprayed every 7 days with only water as a control (CT0). The two plots sprayed with kaolin comprised 40 trees each (4 rows x 10 trees) which were 18 m apart. The plots sprayed with mBAT comprised 72 trees (6 rows x 12 trees) and the control comprised 40 trees (5 rows x 8 trees). These plots were also 18 m apart and were 30 m from the two kaolin treated plots. The mBAT treatment took place from the end of August 2007 to mid-November 2007. In total, nine spray applications were applied on August 31st, September 6th and 17th, October 2nd, 10th, 16th, 23th, 30th and November 11th (Figure 1). Five kaolin applications were applied weekly during October on the 3rd, 11th, 18th, 23rd and 31st, and one additional application was applied on November 11th. For the 14 day kaolin treatment, the four applications were made on October 03rd, 18th; 31st and November 11th. A Maghrebmed trap baited with TML was set up in the centre of each plot to monitor male *C.capitata*. The distance between the traps varied from 30 to 40 m.

Comparison of the effect of kaolin 1.4%, spinosad and malathion-based protein bait spray on Hamlin orange (Kenitra).

The study was carried out from 3/10/2007 to 27/12/2007 in an orchard of orange var. Hamlin. The trial was conducted with a randomized complete block design with two block 12 m apart. Each block comprised five plots of 20 trees each (5 rows x 4 trees). Plots were separated from each other by one row of untreated trees and plastic screens (3 m high x 5 m wide) attached to the side of the tree canopy acted as additional barrier between plots. Each plot received one treatment: two plots were treated with kaolin 1.4% every 7 days (Hk7) and 14 days (Hk14) respectively; one was treated with spinosad every 7 days (Hsp); one was treated with mBAT (HmBAT) and the control plot was sprayed every week with water only (HT0). There were five applications of mBAT in October (October 2nd, 10th, 16th, 23th, 30th) and two in November (8th and 14th) (Figure 1). The kaolin treatments were applied on the same dates as in 2.5.1 above. Six spinosad spray treatments were applied on the same dates as mentioned above for kaolin (7 days). One Maghrebmed trap baited with TML was placed in the centre of each plot; the distance between traps was approximately 32 m.

Comparison of the effect of kaolin 1.4% and deltamethrin-based protein bait spray on Navel orange (Sidi Slimane).

Two separate field trials were conducted in two orchards planted respectively with Navel var. Thomson and Navel var. Washington approximately 60 m apart, located near Sidi Slimane. Navel var. Washington produces rough and firm fruit and is less sensitive than Navel var. Thomson to infestation by key citrus pests. In Navel var. Thomson orchard, the trials were carried out from 13/10/2007 (start of fruit maturation) to 29/11/2007 (harvest), and in Navel var. Washington orchard from 03/10/2007 (fruit immature) to 27/12/2007 (harvest). Each of the two trials consisted of four plots of 80 trees each (8 rows x 10 trees). The plots were separated from each other by either 2 or 3 rows of trees as a buffer. Plastic sheets were used to separate plots, as described above. The following treatments were assigned within each trial: For Navel var. Thomson : kaolin 1.4% sprayed every 7 days (N_1k7), 14 days (N_1k14), deltamethrin-based protein bait applied every 7 days (N_1dBAT) and plot with only water applied every 7 days as control (N_1T0). For Navel var. Washington: kaolin 1.4% sprayed every 7 days (N_2k7), 14 days (N_2k14), deltamethrin-based protein bait applied every 7 days (N_2dBAT) and plot with only water applied every 7 days as control (N_2T0). The date of all spray treatments are mentioned in the Figure 2. One Maghrebmed trap baited with TML was placed in the centre of each plot. The traps in each trial were approximately 55 m apart.

Statistical Analyses

A one way analysis of variance (ANOVA, GLM Procedure) was used to compare male *C.capitata* captures and the fruit infestation between treatments [40] (SAS Institute, 2005). Data were respectively arcsine (√x) and log (x+0.5) transformed before analysis to achieve a normal distribution of residues and homogeneity. The means were separated (homogeneous groups) using the t test (LSD) at P<0.05.

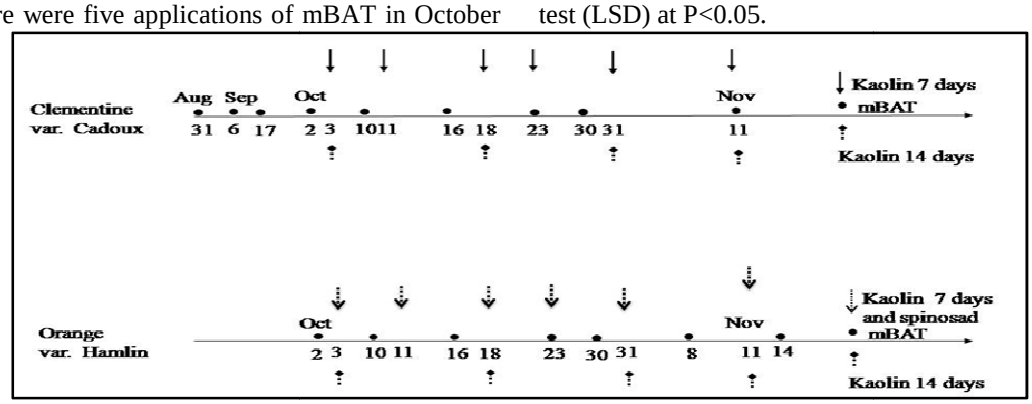

Fig. 1. Legend of the indicated dates of all treatments application for Clementine var. Cadoux and sweet orange var. Hamlin trial at Kenitra

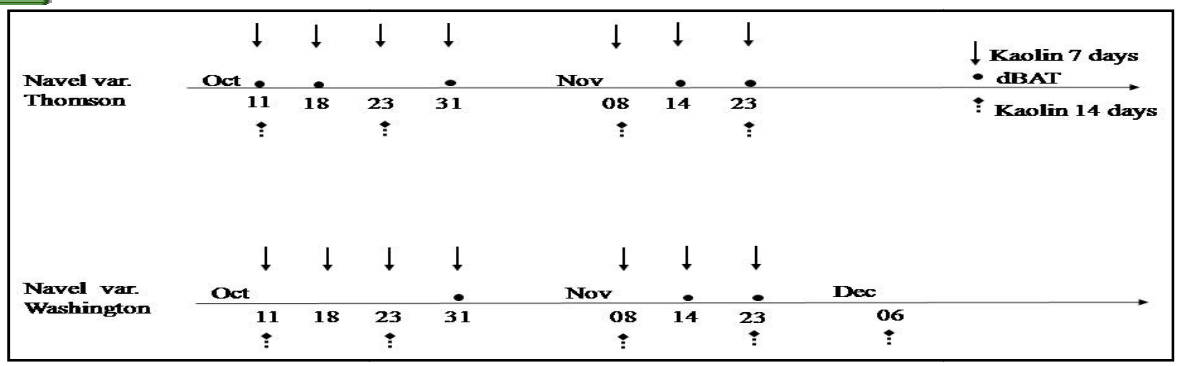

Fig. 2. Legend of the indicated dates of all treatments application for Navel var. Thomson and Navel var. Washington trial at Sidi Slimane.

III. RESULTS

Comparison of the effect of kaolin 1.4% and malathion-based protein bait spray on the Clementine var. Cadoux (Kenitra).

The number of *C.capitata* male captures was reduced in the plots treated every 7 days with kaolin (1.4%) and with mBAT; however, the analysis of variance showed that the reduction was not significant ($F = 2.13$; $df = 3$; $P < 0.1100$) (Figure 3). After kaolin application, the *C.capitata* male captures were very low and reached 4.5 males/trap/day (m/t/d) in Ck7 treatment; compared with the control (8.7), CmBAT (10.4) and Ck14 (15.6). At the end of October, *C.capitata* male captures were 8.2 m/t/d for Ck7, compared with 14.4 for CmBAT, 25.3 for Ck14 and 19.3 for the control. At the beginning of November, captures reached only 14.5 m/t/d for Ck7, compared to 10.5 m/t/d for CmBAT. After mid-November, the *C.capitata* male captures in all plots were decreased. A significant reduction in fruit infestation was observed in the plots treated every 7 days with the kaolin and with malathion-based protein bait compared with the other treatments ($F = 11.17$; $df = 3$; $P = <0.0001$). Fruit infestation in the plot treated every 7 days kaolin (Ck7) was not significantly different to the infestation in CmBAT treatment. Fruit infestation by *C.capitata* increased slowly until the beginning of November with maximums of 0.25% for Ck7 and CmBAT; 0.37% for Ck14 and 1.0% for CT0. The peak period of infested fruits occurred around mid-November with 0.62% for Ck14 and 0.25% for both Ck7 and CmBAT compared with 1.35% CT0. Just before harvest, fruit infestation increased rapidly reaching 2.5% for CT0, 1.75% for Ck14 and 1.25% for CmBAT, compared with only 0.25% for Ck7.

Comparison of the effect of kaolin 1.4%, spinosad and malathion-based protein bait spray on Hamlin orange (Kenitra).

The analysis of variance showed that the number of *C.capitata* male captures was significantly reduced in the plots treated every 7 days with kaolin (Hk7) ($F = 2.81$; $df = 4$; $P : 0.034$) (Figure 4). The captures in the plots treated every 14 days with kaolin, with spinosad (Hsp) and with HmBAT did not differ significantly. At the end of October, the level of *C.capitata* male captures increased in the HmBAT; Hk14 and control (HT0) ranging from 16.5 to 20.0 m/t/d. However, numbers of *C.capitata* male were low in the plot treated every 7 days with kaolin (Hk7)) and spinosad, not exceeding 10.1 m/t/d. At the beginning of November, *C.capitata* male captures were low in the Hk7 treatment (1.1m/t/d) compared with 11.2 for spinosad; 10 for Hk14, 18.3 for HmBAT and 20.7 for the control. After the November, *C.capitata* male captures ranged from 3.2 to 6.2 m/t/d. A significant reduction in fruit infestation also occurred in the plot treated every 7 days with kaolin, and in the mBAT plot, when compared with the other treatments ($F = 28.93$; $df = 4$; $P = <0.0001$). Fruit infestation by *C.capitata* in the Hk7 plot did not differ significantly from infestation in CmBAT plot. Fruit infestation did not exceed 0.5% for Hk7 and HmBAT, and 0.62% for Hk14 compared with two peaks of 0.75% and 0.62% for Hsp at the beginning of November and October respectively. During this last period, infestation did not exceed 1.12% in plot HT0. After December, fruit infestation did not exceed 0.5% in any plots.

Comparison of the effect of kaolin 1.4% and deltamethrin-based protein bait spray on Navel var. Thomson (Sidi Slimane).

The analysis of variance showed that the number of *C.capitata* male captures was significantly reduced in the plots treated every 7 days with kaolin (N_1k7) and with N_1dBAT ($F = 27.30$; $df = 3$; $P = <0.0001$) (Figure 5). *C.capitata* male captures were 7.4 m/t/d for N_1k7, 7.5 for N_1k14, and 4.5 for N_1dBAT, compared with 42.8 for N_1T0. At the beginning of November, captures did not exceed 3.8 m/t/d for N_1k7 or N_1dBAT, compared with 9.2 and 19 for N_1k14 and N_1T0 respectively. Fruit infestation was significantly was less in the plot treated every 7 days with kaolin than in the other treatments ($F = 30.40$; $df = 3$; $P = <0.0001$). Fruit infestation did not differ significantly in the plot treated every 14 days with kaolin (N_1k7) or N_1dBAT. At the end of October, fruit infestation ranged from 0.25 and 0.37% for N_1k7, and from 0.87 to 1% for N_1dBAT, compared with 0.5 to 1.62% for N_1k14, and 2.25 to 2.37% for N_1T0. In mid-November, fruit infestation by *C.capitata* is very low in N_1k7 (0.13%) in comparison with the others treatments: N_1dBAT (1.37%), N_1k14 (1.75%) and N_1T0 (2.75%). The same trend was recorded after this date; fruit infestation in N_1k7 did not exceed 0.75% compared with 1.2 for N_1dBAT and 1.3 for N_1k14 and 2.5 for N1T0 in the mid-December.

Comparison of the effect of kaolin 1.4% and deltamethrin-based protein bait spray on Navel var. Washington (Sidi Slimane).

The analysis of variance showed that the number of *C.capitata* male captures was significantly reduced in the plots treated weekly with kaolin (N_2k7) and with N_2dBAT (F= 3.92; df = 3; P= <0.0173) (Figure 6). The plots treated weekly or every 14 days with kaolin, did not differ significantly. *Ceratitis capitata* male captures decreased from 39.5 to 4.7 m/t/d for N_2k7, and from 28.2 to 6.4 m/t/d for N_2k14, compared with the N_2T0 ranged from 12.5 to 28.5 m/t/d. At the end of October *C.capitata* male captures decreased from 20.2 to 2.7 m/t/d in N_2dBAT. At the beginning of November, *C.capitata* male captures did not exceed 3.2 m/t/d for N_2k7or N_2dbat, compared with 11.2 for N_2k14 or 20.4 for N2T0. At the end of November, the captures did not exceed 5.1 m/t/d in any plots. Fruit infestation was significantly less in the plot treated weekly with the kaolin than in the other treatments (F = 42.97; df = 3; P = <0.0001). Fruit infestation was significantly less in the plot treated every 14 days with the kaolin and N_2dBAT than N_2T0. Fruit infestation ranged from 0.12 to 0.87% for N_2dBAT, and did not exceed 0.5% for N_2k7, and from 1 to 3.25% for the others plots (Figure 12).

IV. Discussion

To produce quality fruit without *C.capitata* infestation requires a choice of control methods which ideally should include environmentally compatible products. This study was designed to evaluate new approaches and alternatives for controlling this pest in citrus orchards using spinosad, kaolin or malathion or deltamethrin-based protein bait application in the Gharb area of Morocco. Monitoring of *C.capitata* males, fruits infestation by *C.capitata* and the use of less toxic insecticide-based protein bait applications which do not leave pesticide residues on fruit are among the basic management practices for controlling this pest. Ground-applied bait applications have been shown to be effective, and are widely used throughout the world [47],[48],[30],[46]**.** In this study we used Trimedlure para-pheromone dispensers to monitor only males *C.capitata*. Kaolin is a mineral compound potentially effective against *C.capitata* on citrus in the condition of Gharb area. The majority of the observations in this study, including citrus fruits infested in the plots treated every 7 days with kaolin, is identical or lower than those treated with malathion-BAT (e.g. Clementine Cadoux and Hamlin varieties at Kenitra), with deltamethrin-BAT (e.g. Navel varieties at Sidi Slimane) or with spinosad bait (e.g. Hamlin).

In this study, for the late citrus varieties such as Navel Washington and Orange Hamlin, only three or fourth spray applications with kaolin was required to minimize fruit infestation to acceptable levels. Plots treated with kaolin showed low *C.capitata* male captures compared to the others treatments. Kaolin effectiveness has been obtained against *C.capitata* on citrus [7] and it has potential for reducing damage caused by *C.capitata* in organic and conventional citrus orchards [20]. No-choice, choice and half-choice laboratory experiments with citrus fruit, nectarines and peaches showed a significant reduction of medfly punctures and landings on kaolin treated fruit [11].

Dipterous species, particularly *C.capitata*, use tactile, olfactory and visual stimuli to reach their hosts [10],[20]. Citrus leaves and fruits treated with kaolin showed a white color which would not be appreciated by female medfly [17],[37],[20]. Behind fruit humidity and optical stimuli, the tactile one is an important component in pre-oviposition behaviour of female *C.capitata*. Thus, kaolin application acts on *C.capitata* with two complementary levels: physical barrier which protects citrus fruit against punctures of *C.capitata* and disturb him to choose a suitable fruit to deposit its eggs and will incite it to go to another more receptive. Also, on several occasions, medfly female were observed to prospect citrus fruits treated with kaolin with a low time of visit compared to fruits treated with water only (M.C. Smaili, own observation).

In this study, treatments every 7 days with kaolin (at 1.4%) or spinosad did not differ and reduced fruit infestation by *C.capitata*. Kaolin (at 1.4%) or Success (spinosad) is regarded as a promising alternative for insecticide-based bait treatment. Similar results for both baited insecticides have been reported for spinosad in controlling *C.capitata* on citrus [8],[9],[46].

Although the formulation spinosad contained in GF-120 needs to be carefully monitored in situations where the release or conservation of parasitoids is a prime concern [50], [13]. These authors suggested that prefeeding mass-reared fruit fly parasitoids with honey before release may not only increase their efficacy but also reduce their risk of feeding droplets of GF-120. Also, the low of toxicity of a natural insecticide such as spinosad, is very attractive to many citrus producers. The efficacy of four alternative insecticides baits on *C.capitata* and their side effects on some natural enemies were evaluated in Spanish citrus agroecosystems [46]. The authors reported that a spinosad bait treatment (Spintor Cebo “named GF-120 in the Americas”, Dow AgroSciencies Iberica, Madrid, Spain) appeared to be the best option when considering pest control efficacy together with the side effects on beneficial arthropods. The negative effects on some parasitoid species should not be overlooked; however Spintor Cebo was the lowest selective bait. Also, in this research, kaolin foliar application was applied during autumn. It is important to note that several papers have saying that kaolin sprays, particularly in spring are detrimental to natural enemies on olive [34] and on citrus [45]. In our conditions, the most actives natural enemies which coincide with the *C.capitata* control period; are the parasitoids *Aphytis melinus* Debach, *Aphytis lepidosaphes* Compere and *Aphytis hispanicus* (Mercet). (Hymenoptera: Aphelinidae) and the coccinellid *Chilocorus bipustulatus* L. (Coleoptera : Coccinellidae) [44].

V. Conclusion

With the combination of regular monitoring, environmental-compatible bait treatment and pest-tolerant

citrus varieties, we believe it is possible to reduce bait treatment to three applications on Navel varieties per season. Our results with kaolin show that it is feasible to use kaolin (only in autumn period) to control *C.capitata* in combination with selected control methods, mentioned above. We consider treatment with kaolin as promising, and should be considered as an important component of an integrated pest management strategy in controlling *C.capitata* in citrus orchards.

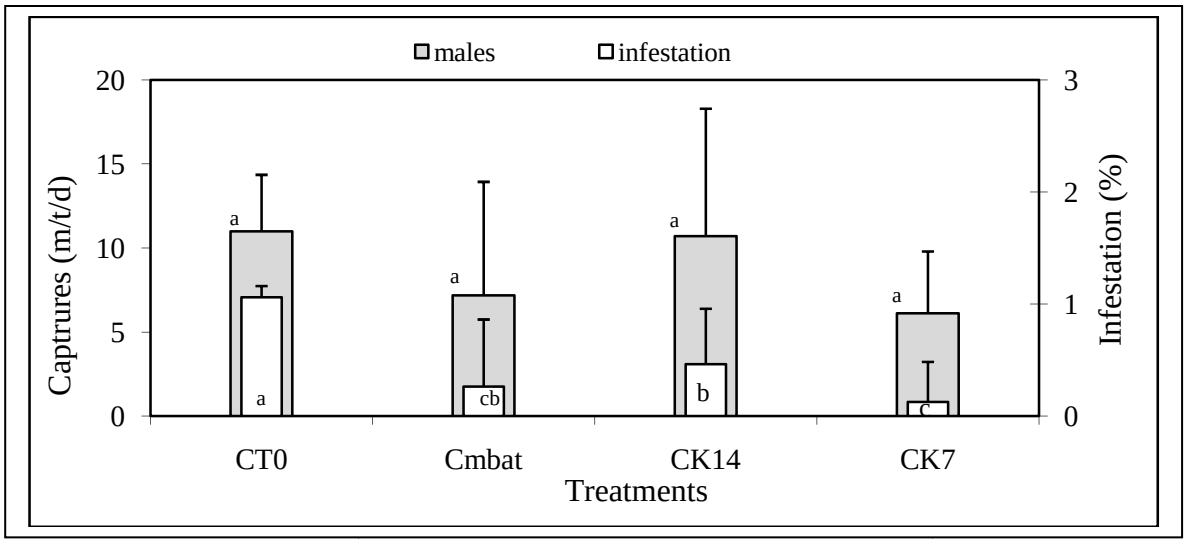

Fig. 3. Mean number of *C.capitata* male caught per trap per day (m/t/d ± SE) and fruit infestation by *C.capitata* in the Clementine var. Cadoux Clementine (% ± SE) at Kenitra. Plots treated with kaolin every 7 days (Ck7), and every 14 days (Ck14), and malathion based protein bait spray (CmBAT), and water only (CT0). For each variable, mean values followed by a different letter are significantly different ($P < 0.05$; LSD test).

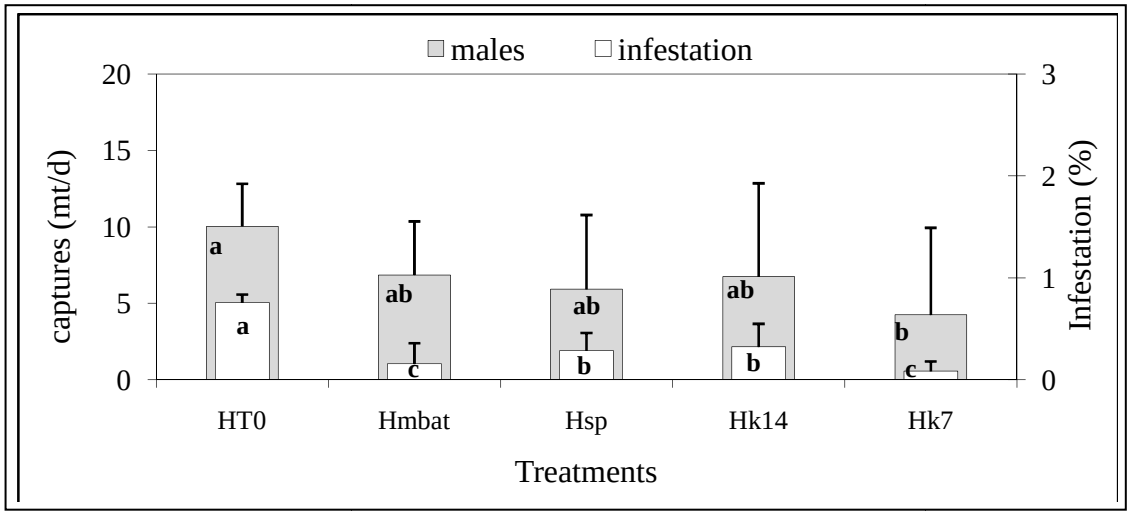

Fig. 4. Mean number *C.capitata* male caught per trap per day (m/t/d ± SE) and fruit infestation by *C.capitata* (%± SE) in the sweet orange var Hamlin orange at Kenitra. Plots treated with kaolin every 7 days (Hk7), and every 14 days (Hk14), and spinosad (Hsp), and malathion-based protein bait spray (HmBAT), and water only (HT0). For each variable, mean values followed by a different letter are significantly different ($P < 0.05$; LSD test).

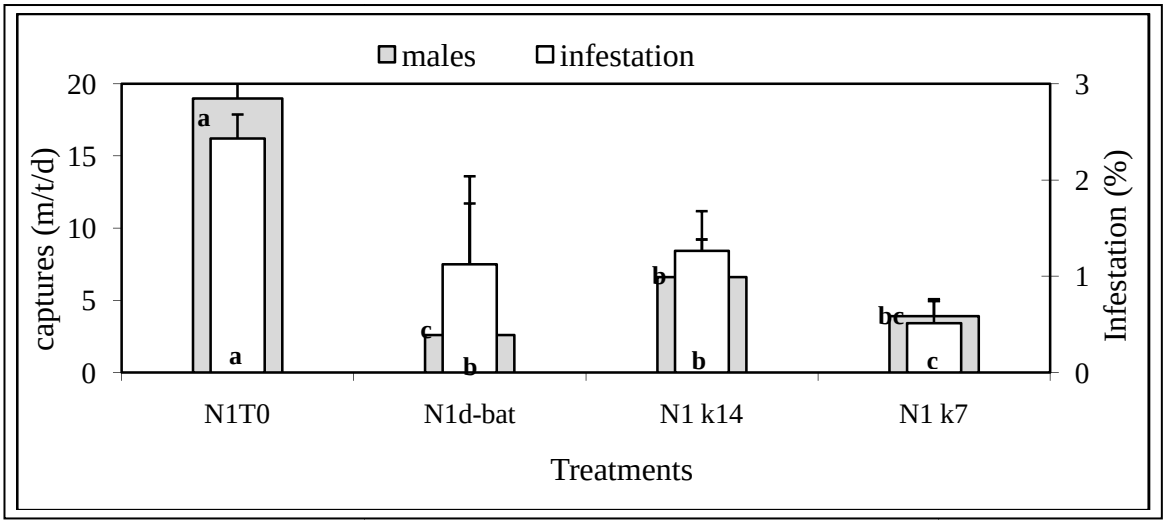

Fig. 5. Mean number of *C.capitata* male caught per trap per day (m/t/d ± SE) and fruit infestation by *C.capitata* (% ± SE) in the Navel var. Thomson (% ± SE) at Sidi Slimane. Plots treated with kaolin every 7 days (N_1k7), and every 14 days (N_1k14), and deltamethrin-based protein bait spray (N_1dBAT), and water only (N_1T0). For each variable, mean values followed by a different letter are significantly different ($P < 0.05$; LSD test).

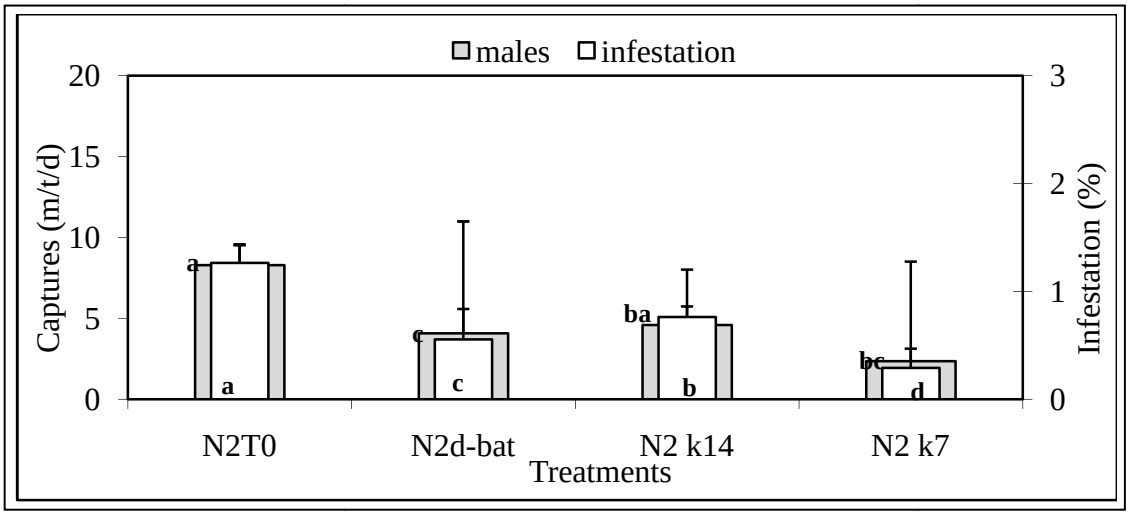

Fig. 6. Mean number of *C.capitata* male caught per trap per day (m/t/d ± SE) and fruit infestation by *C.capitata* (% ± SE) in the Navel var. Washington at Sidi Slimane. Plots treated with kaolin every 7 days (N_2k7), and every 14 days (N_2k14), and deltamethrin-based protein bait spray (N_2dBAT), and water only (N_2T0). For each variable, mean values followed by a different letter are significantly different ($P < 0.05$; LSD test).

ACKNOWLEDGMENTS

The National Agricultural Research Institute (CRRA Kenitra, Morocco) financed this study. The authors are grateful to Dr. Brian BARNES **(**ARC Infruitec-Nietvoorbij Fruit, 7600 South Africa and Technical Consultant*:* FruitFly Africa (Pty) Ltd, Stellenbosch, 7600 South Africa**)** for his critical review of the manuscript. We thank two anonymous referees for useful comments on earlier drafts of the manuscript. We also thank Mohamed Zaghloul (CRRA Kenitra, Morocco), for his technical assistance in the field. Thanks are also extended to all citrus producers which provided plots for the experiment.

REFERENCES

[1] Abbassi, M., (1980). Recherche sur deux homoptères fixés des citrus, *Aonidiella aurantii* (Mask.) (Homoptera : Diaspididae) et *Aleurothrixus floccosus* Maskell (Homoptera : Aleurodidae). *Cahier de la Recherche Agronomique* 35 : 1-168.

[2] Abbassi, M., (1990). Contribution à la lutte biologique contre les homoptères, ravageurs des citrus au Maroc. Doctorat Es. Science Agronomie, Faculté des Sciences Agronomique de Gembloux, Gembloux, Belgique. 191pp.

[3] Abbassi, M., (2010). New pests in Morocco and their natural enemies (1970-2010). In : Garcia-Mari, F. (Ed.), *Proceedings of Working Group "Integrated Control in Citrus Fruit Crops.* IOBC/wprs 1-3 March, 2010, Agadir, Maroc. 237. Abstract.

[4] Benziane, T., (2003). De la lutte dirigée à la lutte intégrée contre les principaux ravageurs en vergers d'˝agrumes au Maroc : cas de la région du Gharb. Thèse de Doctorat ès-Sciences. Université Moulay Ismaïl, Meknès, Maroc. 206 pp.

[5] Boisclair, J., Legault, G., and Stewart, K.A., (2007). Le kaolin : une solution possible pour lutter contre la chrysomèle rayée du concombre (*Acalymma vittatum*). Centre d'Agriculture Biologique de Canada. 1p. http://www.organicagcentre.ca/ResearchDatabase/res kaolin_cucumber.

[6] Boutaleb, J.A., Bouamri, A., and Benziane, T., (2010). Multi-media guide on the pests of citrus fruits in Morocco. In : F. Garcia-Marie (Ed.), *Proceeding of Meeting of Working Group "Integrated Control in Citrus Fruit Crops*". 1-3 March 2010, Agadir, Morocco. 297.

[7] Braham, M., Pasqualini, E., and Ncira, N., (2007). Efficacy of kaolin, spinosad and malathion aginst *Ceratitis capitata* in citrus orchards. *Bulletin Insectology* 60 (1): 39-47.

[8] Burns, R.E., Harris, D.L., Moreno, D.S. and Eger, J.E. (2001). Efficacy of Spinosad bait sprays to control Mediterranean and Caribbean fruit flies (Diptera : Tephritidae) in commercial citrus in Florida. *Florida Entomologist* 84(4): 672-678.

[9] Chueca, P., Monton, H., Ripollés, J.L., Castañera, P., Molto, E. and Urbaneja, A., (2007). Spinosad bait treatments as alternative to malathion to control the Mediterranean fruit fly *Ceratitis capitata* (Diptera: Tephritidae) in the Mediterranean Basin. *Journal of Pest Science* 32(4): 407-411.

[10] Cytrynowicz, M., Morgante, J.S., and De Souza, H.M.L, (1982). Visual response of South American fruit flies, *Anastrepha fraterculus* and Mediterranean flies, *Ceratitis capitata*, to colored rectangles and spheres. *Environmental*. *Entomology* 11 : 1202-1210.

[11] D'Aquino S., A. Cocco, S., Ortu and Schirra, M., (2011). Effects of kaolin-based particle film to control *Ceratitis capitata* (Diptera: Tephritidae) infestations and postharvest decay in citrus and stone fruit. *Crop Protection* 30. 1079-1086.

[12] Delucchi, L., (1964). Ravageurs : deuxième partie. In : Chapot H. & Delucchi V. (Eds), *Les ravageurs des agrumes : maladies, troubles et ravageurs des agrumes au Maroc*. 198-320. INRA, Rabat. Maroc.

[13] Delury, N., Thistlewood, H., and Routledge, R., (2009). Phytotoxicity of GF-120 NF Naturalyte fruit fly bait carried on sweet cherry (*Prunus avium* L.) foliage. *Pest Management Science* 65 : 52-59.

[14] Edwards, R.E., Gerber, C.K., and Hunt, J.G., (2003). A laboratory study to evaluate the toxicity of the Mediterranean fruit fly, *Ceratitis capitata*, bait, Success 0.02 CB, to the honey bee, *Apis mellifera*. *Apidologie* 34 (2): 171-180.

[15] Glenn, D.M., and Puterka, G.J., (2005). Particle films: A new technology for agriculture. *Horticultural Reviews*, 31: 1-44.

[16] Hendrichs, J., Vreysen, M.J.B., Enkerlin, W.R., and Cayol, J.P., (2005). Strategic options in using sterile insect for Area-wide integrated pest management. In: Dyck, V.A. Hendrichs, J. & Robinson, A.S. (Eds), *Sterile Insect Technique. Principles and Practice in Area-Wide Integrated Pest Management*. 563-600. Springer, Dordrecht, Netherlands.

[17] Katsoyannos, P., (1996). Integrated Insect Pest Management for Citrus in Northern Mediterranean Countries. Athens, Greece. Benaki Phytopathological Institute (Ed.). 110 pp

[18] Karagounis, C., Kourdoumbalos , A.K., Margaritopoulos, J.T., Nanos, G.D., and Tsitsipis, J.A., (2006). Organic farming-compatible insecticides against the aphid *Myzus persicae* (Sulzer) in peach orchards. *Journal of Applied Entomology* 130 (3): 150-154.

[19] Larentzaki, E., Shelton, A.M., and Plate, J. (2008). Effect of kaolin particle film on *Thrips tabaci* (Thysanoptera:Thripidae), oviposition, feeding and development on onions: A lab and field case study. *Crop Protection* 27: 727-734.

[20] Levinson, H., Levinson, A., and Osterried, E., (2003).Orange derived stimuli regulating oviposition in the Mediterranean fruit fly. *Journal of Applied Entomology* 127 : 269-275.

[21] Lo, Verde, G., Caleca, V., and Lo-Verde, V., (2011). The use of kaolin to control Ceratitis capitata in organic citrus groves. *Bulletin of Insectology* 64 (1): 127-134.

[22] Jaastad, G., Røen, D., Hovland, B., and Opedal, O., (2006). Kaolin as a possible treatment against lepidopteran larvae and mites in organic fruit production. ecofruit - 12th International Conference on Cultivation Technique and Phytopathological Problems in Organic Fruit-Growing, Weinsberg/Germany, 31.1.-2.2.2006. In: Boos, Markus (Ed.), *Ecofruit - 12th International Conference on Cultivation Technique and Phytopathological Problems in Organic Fruit-Growing: Proceedings to the Conference from 31st January to 2nd February 2006 at Weinsberg/Germany*, Fördergemeinschaft Ökologischer Obstbau e.V. (FÖKO), Traubenplatz 5, D-74189 Weinsberg. 31-35.

[23] Mangan, R., (2005). Population suppression in support of the sterile insect technique. In: Dyck, V.A. Hendrichs, J. & Robinson, A.S. (Eds), *Sterile Insect Technique. Principles and Practice in Area-Wide Integrated Pest Management*. 407-426. Springer, Dordrecht, Netherlands.

[24] Magana, C., Hernandez-Crespo, P., Ortego, F., and Castanera, P., (2007). Resistance to malathion in field populations of *Ceratitis capitata*. *Journal of Economic Entomology* 100 (6) : 1836-1843.

[25] MAPM, (2008). Programme de mise à niveau de la filière agrumicole. Rapport du Ministère de l'Agricultur et de la Pêche Maritime du Maroc , Rabat Janvier 2008. 1-35.

[26] MAPM, 2014. Statistiques du ministère de l'agriculture et de la pêche maritime du Maroc. 2014. Rabat (MR). http://www.agriculture.gov.ma/pages/communiques.

[27] Martinez-Ferrer, M.T., Campos, J.M., and Fibla, J.M., (2012). Field efficacy of *Ceratitis capitata* (Diptera: Tephritidae) mass trapping technique on clementine groves in Spain. *Journal of Applied Entomology* 136. 181-190.

[28] Mazih, A., (2010). Citrus IPM in Morocco: Current status. In : F. Garcia-Marie (Ed.), *Proceeding of Meeting of Working Group "Integrated Control in Citrus Fruit Crops*". 1-3 March 2010, Agadir, Morocco. 266.

[29] Mazor, M., and Erez, A., (2004). Processed Kaolin protects fruits from Mediterranean fruit fly infestations. *Crop Protection* 23: 47-51.

[30] Moreno, D.S., and Mangan, R., (2000). Novel insecticide strategies such as photoxic dye in adult fruit fly control and suppression programs. In: Tan K.H. (Ed.), *Area wide control of fruits flies and others insect pest*. 421-432. Penerbit University. Penang, Sains Malaysia.

[31] Navarro-Liopis, V., Primo, J., and Vacas, S., (2013). Efficacy of attract-and-kill devices for the control of *Ceratitis capitata*. *Pest Management Science* 69(4) : 478–482.

[32] Navarro-Llopis, V., Alfaro, F., Dominguez, J., Sanchis, J. and Primo, J., (2008). Evaluation of Traps and lures for mass trapping of mediterranean fruit fly in citrus groves. *Journal of Economic Entomology* 101 (1): 126-131.

[33] Navarro-Llopis, V., Sanchis-Cabanes, J., Ayala, I., Casana-Giner, V. and Primo-Yufera, E., (2004). Efficacy of lufenuron as chemosterilant against *Ceratitis capitata* in field trials. *Pest Management Science* 60 (9) : 914-920.

[34] Pascual, S., Cobos, G., Seris, E., and Gonzalez-Nunez, M., (2010). Effects of processed kaolin on pests and non-target arthropods in a Spanish olive grove. *Journal of Pest Science* 83. 121-133.

[35] Passino, G.S, Bazzoni, E., Moretti, M.D.L. and Prota, R., (1999). Effects of essential oil formulations on *Ceratitis capitata* Wied (Dipt. Tephritidae) adult flies. *Journal of Applied Entomology* 123: 145-149.

[36] Puterka, G.J., and Glenn, D.M., (2008). Kaolin-based particle films for arthropod control. In: Capinera, J.L. (Eds) *Encyclopedia of Entomology* : *2nd edition*. 2075-2080. Springer. Dordrecht, Netherlands.

[37] Quilici, S., and Rivry, L., (1996). Influence of some visual stimuli on the selection of oviposition site by *Ceratitis* (*Pteranchrus*) *rosa*. In: McPheron, B.A. & Steck, G.J. (Eds),. *Fruit fly pests, a world assessment of their biology and management*. 59-65. St. Lucie, Press Delray Beach, FL, USA.

[38] Sackett, T.E., Buddle, C.M., and Vincent, C., (2005). Effect of Kaolin on Fitness and Behavior of *Choristoneura rosaceana* (Lepidoptera: Tortricidae) Larvae. *Journal of Economic Entomology* 98(5) : 1648-1653.

[39] Saour, G., and Makee, H., (2004). A kaolin-based particle film for suppression of the olive fruit fly *Bactrocera oleae* Gmelin (Dip., Tephritidae) in olive groves. *Journal of Applied Entomology* 128: 28–31.

[40] SAS, 2005. The SAS System for Windows. User's Guide: version 9.1.3, copyright 2002-2005. SAS Institute, Cary, NC, U.S.A.

[41] Showler, A.T., (2002). Effects of kaolin-based particle film application on boll weevil (Coleoptera: Curculionidae) injury to cotton. *Journal of Economic Entomology* 95: 754-762.

[42] Smaili, M.C., Wadjinny, J., and Bakri, A., (2010). Effect of Spinosad, Kaolin and Protein Bait Spray on Mediterranean Fruit fly (Diptera: Tephritidae) Populations in Citrus Orchards in the Gharb (Morocco). In: Sabater, M.B., Navarro-Llopis, V., Urbaneja, G.A. (Eds.), *Proceeding of the 8th International Symposium on Fruit Flies of Economic Importance*. Valencia, Spain, 2010, Abstract.

[43] Smaili, M.C., Afellah, M., Zrida, L., and Aarab, A., (1999). Trapping and evaluation of the bait spray to control Medfly in citrus in Gharb area(Morocco). *Med Fac.Landboww*. 64/3a: 69-175.

[44] Smaili, M.C., Abbassi, M., Boutaleb, J.A., and Blenzar, A., (2013). Richesse spécifique des ennemis naturels associés aux vergers d'agrumes au Maroc : Intérêt et implication pour la lutte biologique. *EPPO Bulletin* 43 (1): 155-166.

[45] Smaili, M.C., El Ghadraoui, L. , Gaboun, F., Benkirane, R., and Blenzar, A., (2014). Impact of some alternative methods to chemical control in controlling aphids (Hemiptera : Sternorrhyncha) and their side effects on natural enemies on young citrus Moroccan groves. *Phytoparasitica* 42: 421-436.

[46] Urbaneja, A., Chueca, P., Monton, H., Pascual-Ruiz, S., Dembilio, O., Vanaclocha, P., Abad-Moyano, R., Pina, T. and Castanera, P., (2009). Chemical Alternatives to Malathion for Controlling *Ceratitis capitata* (Diptera: Tephritidae), and Their Side Effects on Natural Enemies in Spanish Citrus Orchards. *Journal of Economic Entomology* 102 (1) : 144-151.

[47] Vincenot, D., and Quilici, S., (1993). Ile de la Réunion : Développement de lutte intégrée en verger d'agrumes. *Phytoma* 456 : 43-46

[48] Vincenot, D., and Quilici, S., (1995). Lutte raisonnée en verger d'agrumes à l'Ile de la Réunion ; expérimentation et développement. *Fruits* 50 (1) : 27-38.

[49] Villanueva, R.T., and Walgenbach., J., (2007). Phenology and management of the apple maggot and effects of Surround on its behavior in North Carolina. *Crop protection* 26:1404-1411.

[50] Wang, X.G., Jarjees, E.A., Mcgraw, B.K., Bokonon-Ganta, A.H,. and Messing, R.H., Johnson, M.W. (2005). Effect of spinosad based fruit fly bait GF-120 on Tephritid fruit fly and aphid parasitoids. *Biological Control* 35. 155-162.

[51] Wyss, E., and Daniel, C., (2004). Effects of autumn kaolin and pyrethrin treatments on the spring population of *Dysaphis plantaginea* in apple orchards. *Journal of Applied Entomology* 128: 147–149.