

Red Palm Weevil (*Rhynchophorus ferrugineus*) Chemical Treatments Applied on Ornamental Palms in Tunisia: Results of Extensive Experiments

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Abstract – The red palm weevil (RPW), *Rhynchophorus ferrugineus* Oliv, (RPW) (Curculionidae: Coleoptera), is an economically important, tissue - chewing pest of date palm in many parts of the world. The invasion of Red palm weevil (*Rhynchophorus ferrugineus*) to Tunisian ornamental palms was detected in 2011. It has begun a real threat to date palms *Phoenix dactylifera*. Chemical control becomes an essential mean to recover infested palm trees. In this study, we evaluated several chemical products: Spinetoram + sulfoxaflor, Imidacloprid, Thiametoxam, XDE-607 and Emamectin benzoate against RPW at different localities in Tunis. Palms were selected randomly based on visual symptoms. Three methods of chemical delivery were used: powdering, irrigation and injection. This study revealed that the use of Imidacloprid 5% (Suxon mini) by irrigation with the dose of 500 g/Palm give better results in protecting the palm. Emamectin benzoate shows significant efficacy using the product: Pro-act while applying a dose of 100 ml/palm.

Keywords – Red Palm Weevil, Ornamental Palm Trees, Imidacloprid, Emamectin Benzoate, Thiametoxam, Spinetoram, spinetoram + sulfoxaflor, Endotherapy.

I. INTRODUCTION

The red palm weevil (RPW), *Rhynchophorus ferrugineus* Olivier (Coleoptera: Curculionidae), is one of the most severe pests of various palm species, including ornamental palms ([1]; [2]; [3]; [4]).

RPW is originally from South Asia where it is a major pest of coconut. In the Mediterranean basin RPW has become a key pest of *P. canariensis* which is extremely sensitive to its attack [4].

By the mid-1980's, multiple introductions of *R. ferrugineus* to the Middle East from Pakistan and India have occurred and the Asian palmweevil (APW) is now a serious pest of date palms, in the Arab Gulf States.

The rest of the Mediterranean countries were totally infested by 1994, eventually to report the pest attack in North America in 2009 [5].

The RPW reportedly attacks over 26 species of palm belonging to 16 genera globally in several regions of the world.

In the Mediterranean basin it has moved to Africa and Europe, mainly due to the movement of infested planting material. As concerns Italy, RPW severely damages overall *Phoenix (P.) canariensis*. Since then it has quickly spread in almost all areas where *P. Canariensis* was present, resulting in rapid death of thousands of plants [4].

The latest report of an RPW invasion occurred in late 2011 in Tunisia where it was found infesting *Phoenix canariensis* [3]. As the eggs of RPW are deposited inside

concealed places of the stem, The creamy white color larvae (grubs) are the most destructive stage. These legless larvae feed on the succulent plant tissues that create feeding galleries and move towards the center of the infested palms. Such feeding pattern disrupts the vascular system of the infested palm resulting toppling, collapse and death of the infested palm under severe attack. A very typical sign of infestation is the distorted growing point at the top of the palm. The growth at the top of the canopy can become deformed and offset. This distortion is a very common symptom and is more easily seen than other symptoms of infestation.

A 0–4 scale has been developed to characterize the stages of RPW infestation, where 0 represents an infested date palm showing no stages of the pest or damage symptoms, while 4 indicates a RPW-infested date palm that has toppled [6].

This scale has been adapted in our study to evaluate the palm trees 'infestation stages.

Life cycle is than wholly sealed within the stem upon emergence of the adults from the cocoon which fly out and infest new palms or remain in the same palm and cause re-infestations at a new site [7].

The existing methods of RPW management largely rely on the integrated pest management IPM strategies, which include: phyto sanitation, use of conventional insecticide, pheromone traps and bio-control agents. The chemical control method against RPW, include regular surveillance as the first necessary step for a swift detection, spraying and injecting of synthetic insecticides into infected palms [8].

Preventive and curative methods were often based on chemical pesticides, until an extended alternative has been introduced involving the use of natural enemies ([7]; [8]) including nematodes, bacteria, and fungi have shown variable results in terms of larval and adult mortality.

Even though highly effective pesticides exist. There are many problems related both to the delivery of the product to the target (tunneling larvae within the palm) and also regarding the ecotoxicological profile of these chemicals. New environment friendly products are urgently needed, and alternative application methods (such as trunk injection) or uptake mechanisms (such as systemic products) have already been demonstrated ([9], [10]).

Imidacloprid [1-(6-chloro-3-pyridylmethyl)-2-nitroimino-imidazolidine] possess both systemic and contact mode of action and is compatible with different application methods for example foliar application, seed treatment [11], soil drench and stem application in different crops and trees [10]. Imidacloprid causes

irreversible blockage of postsynapticnicotinic acetylcholine receptor of the central nervous system [12]. Laboratory and semi-field trials of Imidacloprid (SL) against RPW has been reported by Cabello et al. [13] and Kaakeh, [14] which strengthen the case for its further evaluation against RPW having different geographical origin.

II. MATERIALS AND METHODS

1. Study Sites

In this article we treated 2 experimental fields included within the regions concerned by the trapping campaign (Ariana and Carthage). Each site was marked by its population of stems and the density of plantation.

2. Testing the Effectiveness of Different Active Substances Injected

2.1. Application of Endotherapy Treatments

The injection of palms with a systemic product is one of the main methods of control of the red weevil. The implementation of this method depends on the persistence of the product used. This method requires the use of specific equipment: A current generator for the drill at any point of the processing site, a drill For the perforation of the holes at the level of stipe, the injectors as support for the passage of the product in the stipe and the product used.

The application of the injection treatment is carried out while passing through the following steps:

- *Step 1: Preparation of the insecticide solution.
- *Step 2: Drilling the holes to be made in the screwing (clockwise) position and in the percussion (hammer) position on which a wooden drill bit 30 to 40 cm long and 12 mm of diameter (Figure 1)
- *Step 3: Insert the recessed injectors of about fifteen cm into the hole (Figure 2).
- *Step 4: Pesticide was delivered into the palm trunk using specialized pesticide delivering system (Figure 3).



Fig. 1. Drilling a brad point drill-bit into the sapwood.



Fig. 2. Inserting plugs into the boreholes.



Fig. 3. Injecting the insecticide into the plugs.

2.1.1. Tested Active Substances in Carthage

Three active substances were tested in Carthage: Dimethoate, Thiametoxame and Imidaclopride, the products and doses are shown in Table 1.

The test is done on the 03/12/2016 in two sites: Thermes d'Antonin and Villa Ben Ayed. In each site, 5 palms were treated by each product.

Table 1. Active Substances Applied in Carthage

Code	Product	Active substance	Prepared solution	Dose/Palm
S	Synara	Thiametoxam	25 g/L	400 cc
D	Biomat	Dimethoate	66,66g/L	400 cc
C	Confidor	Imidaclopride	33,33g/L	400 cc

200

2.1.2. Tested Active Substances in Ariana

Various tests have been carried out in different sites in the governorate of Ariana.

At various sites in Ariana (Kawech and Soltani houses), a total of 70 palms were treated by injection of systemic products on 29/03/2016, at a rate of 10 palm trees per product with the following doses and products respectively in the table below.

Table 2. Active Substances Applied in Ariana (quantity of product dose 1 and dose 2)

Code	Product	Active substance	Dose 1	Dose 2
A	GF-3052	Spinetoram+sulfoxaflor	5g	10g
C	synara	Thiametoxam	7,5g	10g
D	Proclain	Emamectina benzoate	5g	10g
D'	Pro-Act	Emamectina benzoate	80 ml	100 ml
G	Confidor	Imidaclopride	10ml	12ml
B	GF-3441	XDE-607	5g	10g

The treatment was redone on 10/08/2016 after 4 months 13 days.

Before processing, the 70 palms were analyzed to count the infested palms and their stages of infestation.

2.1.3. Evaluation of Treatments

The effect of treatments was assessed on the basis of three parameters: active substance content (leaf pesticide residue analysis), number of insects inside the palm after slaughter, Evolution of the attack.

1.1.3.1. Analysis of Pesticide Residues

Samples for analysis were collected from the two plots of Carthage in different dates (after 7 days, 14 days, 21 days, 1 month and 45 days). From each palm tree two samples are taken, the first sample of which is a central palm and the second is taken from the peripheral fins. The samples were placed in plastic bags (Figure 4) while mentioning the sample code and the date of collection. Then, in the laboratory, the fins are totally crushed in a very fine way and analyzed at the pesticide laboratory in the General Directorate for the Protection and Quality Control of Agricultural Products.



Fig. 4. Samples of palms after treatment taken for analysis.

Detection of the active substance content at the level of the fins was carried out by the LC / MS / MS method (liquid chromatography coupled with mass spectrometry). Indeed, it is an analytical method that combines the performances of liquid chromatography and mass spectrometry in order to identify and / or quantify precisely many substances. An LC-MS unit is composed of two main blocks: a liquid chromatograph and a mass spectrometer.

1.1.3.2. Number of Insects Inside the Palm

After the slaughter of the attacked palms, all the stages of the insect present are quantified and placed in boxes. The sorting of insects must be done carefully so as not to leave any cocoon or living adult that can cause another attack (Figure 5).



Fig. 5. Sorting of rpw stages in slaughtered palms.

2.1.3.3. Controlling the Efficacy of the Treatment by Standard Palm Weevil Black Trap

The black trap as it is described in [4] is a 10 L plastic bucket. Trap height was 40 cm, and the diameter of the top and bottom was 18 cm. Each trap had 3 equidistant circular (5cm width) openings whose lower limits are tangent to the ground surface to allow *R. ferrugineus* entrance (Fig.6).

Each trap contained one aggregation pheromone dispen-

-ser ISCA and one kairomone capsule that were attached to the lower surface of the trap For the bait and the fermentation substances dates and water were used respectively and were regularly changed each 15 days.



Fig. 6. A black bucket trap used for the capture of RPW.

2.2. Spray Treatment of Suxon (5% Imidacloprid)

In the site (Bouchammaoui House), 8 palms were treated with 5% sulphate granulated at 100 g / palm and 10 palms by 5% suxon at a dose of 50 g / palm. The first application of the treatment was made on 26/04/2016 than the treatment was repeated on 14/10/2016.

On the day of first treatment 4 palms were infested in stage 1 of attack. The survey made on 14/10/2016 did not show any infested palm. During the last survey carried out on 07/12/2016, infestation was not observed in palms treated with granulated suxon, after a period of 6 months for the first treatment and only after about two months for the last treatment, which confirms well the efficacy of the suxon product 5% with respect to the red palm weevil.

In addition, at the National Guard site of the Aouina, on 11/08/2016 65 palms were treated by foliar spraying (Figure 7) with liquid Confidor at a rate of 60cc / hl. Once, no infestation was recorded 2 months after treatment (Stationary situation) on the other hand two palm trees were attacked 4 months after treatment with the appearance of new healthy palms for the attacked and treated palms .. Which means that the treatment with liquid confidor by spraying is often enough.



Fig. 7. Spraying confidor on infested palm tree (first infestations).

2.3. Application of Granulated Suxon 5G (Imidacloprid Granulated) by Irrigation

At the site of Ariana (Moncef Elkawech house), 12 palms were treated by the granulated Suxon 5G (Imidacloprid granulated) applied by irrigation (Figure 8) at the rate of 500g of the product / palm. When the treatment was applied, 5 palms were attacked at stage 1 and 1 palm was attacked at stage 2.

During the survey made on 07/12/2016, only one palm was attacked in stage 1 and only one palm was attacked in stage 2.

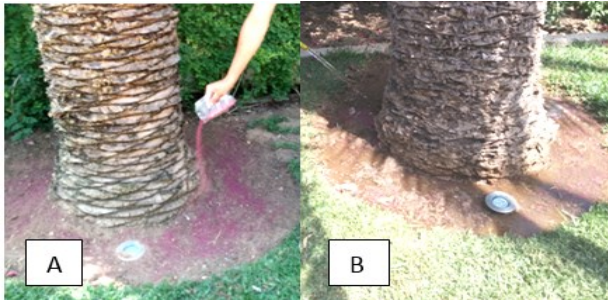


Fig. 8. A) powdering Imidacloprid (SuXon) under the trunk, B) irrigating the treated palm with water.

III. RESULTS

1. Efficacy of injected active substances

1.1. Efficacy of the treatment by endotherapy in Carthage

1.1.1. Detection of the Active Substance content

Three active substances were tested in two sites in Carthage: Thiametoxam, Dimethoate and Imidacloprid. The analysis of pesticide residues in the samples treated by the three products tested shows the very slow upward movement of thiametoxam (S11, S21) and its absence after two weeks.

Imidacloprid (C) and Dimethoate (D) have the same appearance. A minimum amount detected after one week of treatment, then this amount increases slightly and begins to decrease in two months (Figure 9 and 10).

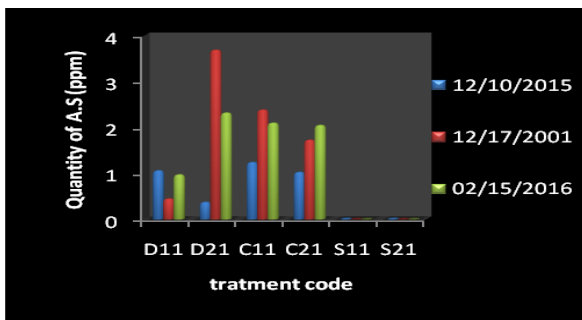


Fig. 9. Evolution of active substance quantity on palms in site 1 (Therme of Carthage).

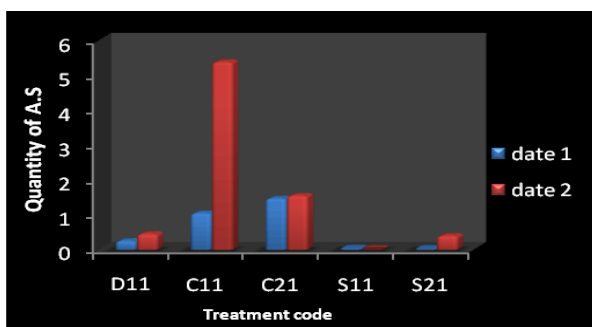


Fig. 10. Evolution of active substance quantity on palms in site 2 (Ben Ayed house :Carthage)

1.1.2. Number of Insects Inside the Palm

In the two sites of Carthage (Ben Ayed and Therme), the count of the RPW stages present in slaughtered palms shows the major presence of solid cocoons and live larvae which is the main cause of attack progress in palms treated with Synara (S1a, S1b and S1c), of which thiametoxam is the Active Substance.

The other two A.S used show almost the same number of insect stages present that is close to that in untreated palms (Figure 11 and 12).

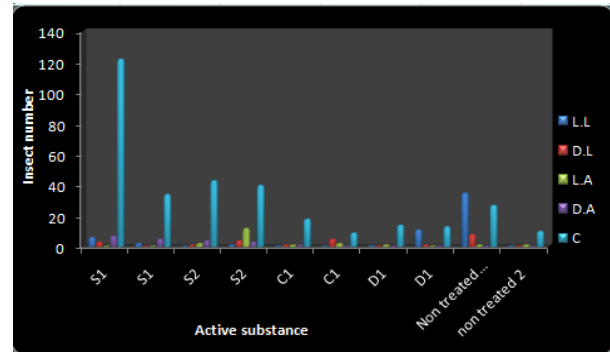


Fig. 11. count of the RPW stages present in slaughtered palms in site 1 (Therme of Carthage).

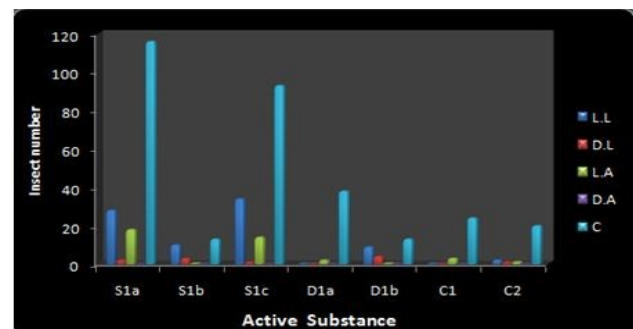


Fig. 12. count of the RPW stages present in slaughtered palms in site 2 (Ben Ayed house : Carthage).

1.2. Efficacy of the Treatment by Endotherapy in Ariana

In this site, the efficacy of 6 Active Substances applying two doses of each product was compared.

The results shown in (Fig.13) revealed that the mean number of individuals decreased considerably, from 15 individuals/trap in the beginning of treatment (APRIL) to 1 individual in July.

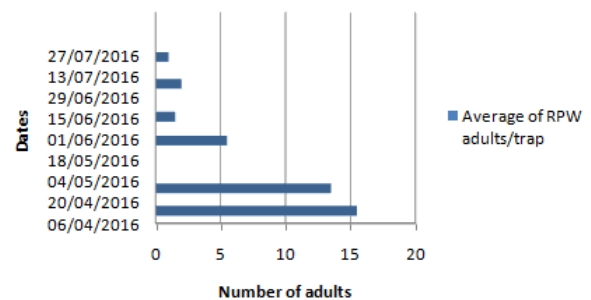


Fig. 13. Evolution of RPW adults' number/pheromone trap in site Soltani house (Ariana).

Controlling the evolution of attack of treated palms we note that the least effectiveness is that using the two active substances (A: Spinetoram+Sulfoxaflor and C: thiametoxa-m).

The treated palms using Imidacloprid and XDE-607 are initially healthy and remain healthy towards the last control date, which implies the good use of these Active substances in preventive treatment.

Palms treated with emamectin benzoate (D and D') become healthy (Figure 14).

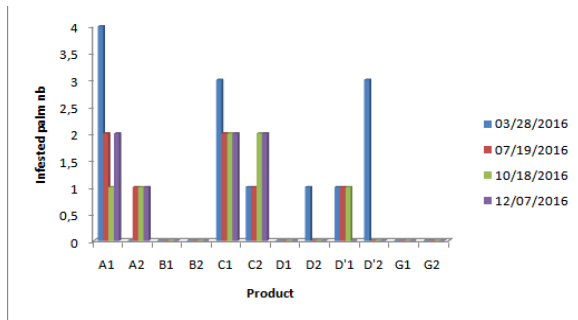


Fig. 14. Infest palm number evolution in Soltani and bakkar houses (Ariana).

The efficacy of emamectine benzoate and Imidacloprid has been proven by the analysis of pesticide residues marked with the absence of Thiametoxam, Spinetoram and the presence of Imidacloprid and emamectim benzoate using the second dose (product: pro-act)

2. Efficacy of Spray Treatment of Suxon (5% Imidacloprid)

2.1. Bouchammaoui House

The treatment applied in this site is Imidacloprid 5% (SuXon Mini). In order to find the optimum dose, we tested 2 doses 100g/tree and the second dose is 50g/tree . We repeated the treatments twice in the following dates (First treatment 26/04/2016, second treatment 14/10/2016)

In each controlling visit, we counted the individuals' number captured in each pheromone trap. The results are represented in (Fig.15). Using the scale 0-4 (mentioned in introduction) we examined the symptomatology of each palm tree in order to detect the evolution of palm tree infestation by the pest.

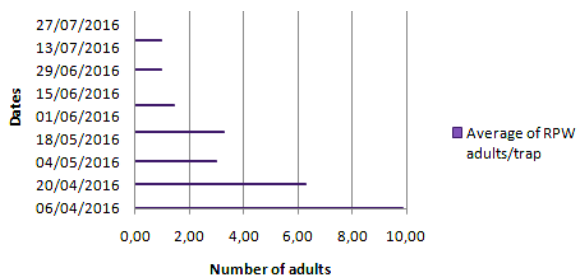


Fig. 15. Evolution of RPW adults' number/pheromone trap in Bouchammaoui house.

The results shown in (Fig.16) revealed that the mean number of individuals decreased considerably, from 9 individuals/trap in the beginning of treatment (APRIL) to 1 individual in August.

Evolution of Palm Infestation

After comparing the palm trees treated with imidaclopride 5% at the dose 50g/tree and others treated with 100g/tree, we didn't notice a huge difference. The infestation rate decreased from stage 1 to stage 0 (Fig 14).

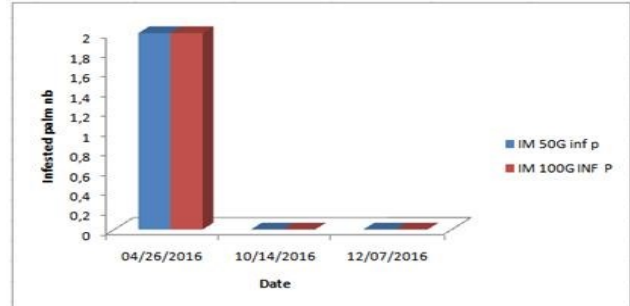


Fig. 16. Infest palm number evolution in Bouchammaoui house (Ariana).

2.2. Pastor Institute

The infested palms of Pastor Institute were treated by spraying confidor. The applied dose was 0.035L/hl of water .

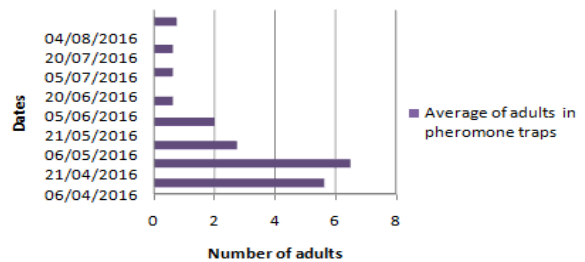


Fig. 17. Evolution of RPW adults' number/pheromone trap in Pastor Institute.

During five months from APRIL to AUGUST we controlled the evolution of RPW adults captured in seven pheromone traps in the infested site. The results shown in (Fig.17) revealed that the mean number of RPW captured in traps decreased from 7 in to one in August. It is obviously to notice that the persistence of Imidacloprid in palm trees affects the evolution of the pest population.

• Evolution of Palm Infestation

After comparing the palm trees treated with imidaclopride, we didn't notice a huge difference. The infestation rate decreased from stage 1 to stage 0 (Figure 18).

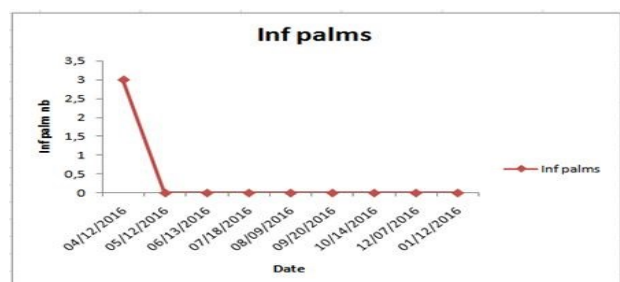


Fig. 18. Infest palm number evolution in Bouchammaoui house (Ariana).

3. Efficacy of Granulated Suxon 5G (Imidacloprid Granulated) by Irrigation

This site was treated with pellets of Imidacloprid 5% (suxon mini). Each palm was treated by irrigation at the dose of the insecticide 500g/tree.

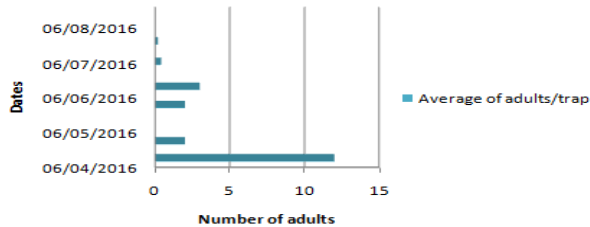


Fig. 19. Evolution of RPW adults' number/pheromone trap in Moncef Elkawech house (Ariana).

The results shown in (Fig. 19) reveal that the pellet of Imidacloprid adults' number decreased. This product is characterized by a long persistence in the soil which is beneficial for the palm tree protection. It is repellent for the pest.

Evolution of Palms Infestation

In this site, six palm trees were initially infested. The irrigation by Imidacloprid 5% (Suxon mini) showed considerable results in reducing the infestation level with RPW. The last visit to this site took place in December 2016. All the palm trees treated were in situation S0 (no infestation registered) (Figure 20).

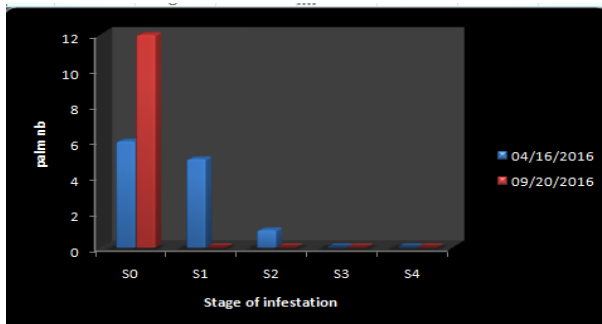


Fig. 18. Infest palm number evolution in Bouchammaoui house (Ariana).

IV. DISCUSSION

The decrease of the adults' number in all the pheromone trap after treating palm trees reveal that these latter have an impact on RPW populations. It was found in our study that injection in the top of the palm near the apex of the palm is more efficient in controlling the pest. In fact it has been proven that larvae prefer apical bud and their activity is more accentuated near that region [5]. Therefore injecting the insecticide there may eliminate the maximum of grubs, the most damaging stage of the insect. During our study, we faced the problem of stealing injection cannula made of copper (due to the value of this metal nowadays). We substituted these tubes by others with rigid plastic (Fig.12) and the results seemed the same. Using Imidacloprid 5% (Suxon) with the dose 500g/palm seemed more efficient in controlling RPW. In order to optimize

the frequency of applying insecticide, we tested two doses. It was proved that applying 50 g is efficient as much as 100g/palm. Therefore, thinking environmentally and economically it is better to use 500g of Imidacloprid 5% per palm. For Thiametoxam and Sulfoxaflor with Spinetoram, it was better to use the dose 10g/palm with injection repeating the treatment every 2 months. The results showed that is the optimum dose to recover the insect infestation.

The efficacy of emamectine benzoate and Imidacloprid using the higher dose has been proven

V. CONCLUSION

The persistence of the substances tested in this study seemed to be promising to fight RPW unless we repeat the treatment frequently. For Thiametoxam and Imidacloprid liquid (confidor), we recommend repeating the application each three months with a rotation of insecticides in order to avoid the resistance phenomenon. Although injection seemed to be a promising method and more efficient in controlling the pest, drilling a high number of injection holes will create in the long run a risk to the health of the palms or to their mechanical resistance. Increasing the diameter of the holes to eliminate the sealing barrier at each treatment will weaken the palms resistance in the long term [9]. Emamectin Benzoate as biopesticide is good for Red Palm weevil control, Thiametoxam, Spinetoram. This study revealed that the use of Imidacloprid 5% (Suxon mini) mixed with soil and without adding water give better results in protecting the palm. In fact the pellets of Suxon mini release the Imidacloprid for a long run under standard conditions. The palm is most the time protected from the insect attack.

In conclusion, all of these chemicals tested, regardless of the method used, have been found at the level of the top of the palm tree and protect somewhat the treated palms, but what differs is their persistence, which has not exceeded the three months, Except for Emamectin Benzoate, Spinetoram + sulfoxaflor and imidacloprid 5G, their persistence may exceed six months, so these substances can be used in the national campaign against the red palm weevil.

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