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Table of Contents

SURVEY

Automatic localization of phoenix by satellite image analysis. R. Cousin and M. Ferry (Spain)**.** Pages 83-88
http://dx.doi.org/10.22268/AJPP-037.2.083088

QUARANTINE

Is policy paralysis on quarantine issues in the Near East and North Africa region leading to the buildup and spread of red palm weevil, *Rhynchophorus ferrugineus*?. S.B. Balijepalli and J.R. Faleiro (India). Pages 89-100
http://dx.doi.org/10.22268/AJPP-037.2.089100

NATURAL ENEMIES

***Billaea rhynchophorae,* a palm weevil parasitoid with global potential.** B. Löhr, A. Negrisoli and J.P. Molina (Colombia & Brazil). Pages 101-108
http://dx.doi.org/10.22268/AJPP-037.2.101108

CONTROL

The world situation and the main lessons of 30 years of fight against the red palm weevil. M. Ferry (Spain). Pages 109-118
http://dx.doi.org/10.22268/AJPP-037.2.109118

Studies on curative treatment of red palm weevil, *Rhynchophorus ferrugineus* Olivier infested date palms based on an innovative fumigation technique. S.R. Al Ballaa and J.R. Faleiro (Saudi Arabia & India)**.** Pages 119-123
http://dx.doi.org/10.22268/AJPP-037.2.119123

A simple and low cost injection technique to protect efficiently ornamental Phoenix against the red palm weevil during one year. S. Gomez and M. Ferry (Spain). Pages 124-129
http://dx.doi.org/10.22268/AJPP-037.2.124129

Early detection and preventive control of *Rhynchophorus ferrugineus* (Coleoptera Curculionidae): a quarantine pest in Brazil. V.A. Dalbon, J.P.M. Acevedo, A.E.G. Santana, H.F. Goulart, I. Laterza, A. Riffel, A. Negrisoli Jr, B. Lohr and F. Porcelli (Brazil, Colombia & Italy). Pages 130-135
http://dx.doi.org/10.22268/AJPP-037.2.130135

Studies on service free semiochemical mediated technologies to control red palm weevil *Rhynchophorus ferrugineus* Olivier based on trials in Saudi Arabia and India. J.R. Faleiro, A.-M. Al-Shawaf, H.A.F. El-Shafie and S. Pai Raikar (India & Saudi Arabia). Pages 136-142
http://dx.doi.org/10.22268/AJPP-037.2.136142

Microwave heating: a promising and eco-compatible solution to fight the spread of red palm weevil. R. Massa, G. Panariello, M.D. Migliore, D. Pinchera, F. Schettino, R. Griffo, M. Martano, K. Power, P. Maiolino and E. Caprio (Italy). Pages 143-148
http://dx.doi.org/10.22268/AJPP-037.2.143148

Efficiency of food baits, synthetic attractants and trap type on *Rhynchophorus ferrugineus* (Olivier) trapping in palm plantations, Ismailia, Egypt by aggregation pheromone traps. A. El-Banna, M.K. Abbas, A. Hala and T.M. Ibrahim (Egypt). Pages 149-150
http://dx.doi.org/10.22268/AJPP-037.2.149150

Policies to control red palm weevil based on the recommendations of the Rome meeting. S. Al-Dobai (Italy). Pages 151-152
http://dx.doi.org/10.22268/AJPP-037.2.151152

Controversial aspects about red date palm weevil. H.Y. Al Ayedh and A.M. AlJber (Saudi Arabia)**.** Pages 153-155
http://dx.doi.org/10.22268/AJPP-037.2.153155

Date palm value chain development and the control of red palm weevil in Egypt. M.K. Abbas and Th. Yaseen (Egypt). Pages 156-157
http://dx.doi.org/10.22268/AJPP-037.2.156157

The effect of preventive measures in reducing red palm weevil infestation. M.K. Abbas (Egypt). Pages 158-158
http://dx.doi.org/10.22268/AJPP-037.2.158158

INTEGRATED MANAGEMENT

Importance of field operations for reducing red palm weevil (RPW) infestation on date palm. M. Ben Salah (Oman). Pages 159-162
http://dx.doi.org/10.22268/AJPP-037.2.159162

Management of the Red Palm Weevil *Rhynchophorus ferrugineus* (Olivier) using sustainable options in Saudi Arabia. M. Ali-Bob (Saudi Arabia). Pages 163-169
http://dx.doi.org/10.22268/AJPP-037.2.163169

Overview of the gaps, challenges and prospects of red palm weevil management. J.R. Faleiro, M. Ferry, Th. Yaseen and S. Al-Dobai (India, Egypt & Italy). Pages 170-177
http://dx.doi.org/10.22268/AJPP-037.2.170177

Red palm weevil (*Rhynchophorus ferrugineus* Olivier): Recent advances. F. Gonzalez, S. Kharrat, C. Rodríguez, C. Calvo and A.C. Oehlschlager (Costa Rica & Tunisia). Pages 178-187
http://dx.doi.org/10.22268/AJPP-037.2.178187

An effective strategy to obtain very rapidly the red palm weevil decline in an area planted with ornamental palms. M. Ferry, R. Cousin, D. Chabernaud and F. Ferrero (Spain & France). Pages 188-197
http://dx.doi.org/10.22268/AJPP-037.2.188197

BIOLOGICAL CONTROL

Efficacy of insect pathogenic fungi on mortality and development of *Rhynchophorus ferrugineus* (Olivier). W. Wakil, M. Usman and S. Gulzar (Pakistan). Pages 198-199
http://dx.doi.org/10.22268/AJPP-037.2.198199

Is the use of entomopathogenic fungi a viable option for the control of Red Palm Weevil?. M. El Bouhssini. A.N. Trissi and Z. Kadour (Morocco & Syria). Pages 200-202
http://dx.doi.org/10.22268/AJPP-037.2.200202

FORECASTING

Red palm weevil monitoring and early warning system. K. Cressman (Italy). Pages 203-204
http://dx.doi.org/10.22268/AJPP-037.2.203204

ECONOMIC IMPACT

The economic impact of red palm weevil *Rhynchophorus ferrugineus* Olivier in Egypt. M.K. Abbas (Egypt). Pages 205-205
http://dx.doi.org/10.22268/AJPP-037.2.205205

مجلة وقاية النبات العربية
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وقائع المؤتمر الدولي: نحو مقاربة ابتكارية ومستدامة لمكافحة سوسة النخيل الحمراء
الذي عقد في باري، إيطاليا، 23-25 تشرين الأول/أكتوبر 2018
والذي نظمه المركز الدولي للدراسات الزراعية المتقدمة لمنطقة البحر الأبيض المتوسط - باري
ومنظمة الأغذية والزراعة التابعة للأمم المتحدة

جدول المحتويات

حصر

التحديد التلقائي لمواقع أشجار النخيل باستخدام الصور الفضائية. رفائيل كوزان وميشيل فيري (إسبانيا). الصفحات 83-88
http://dx.doi.org/10.22268/AJPP-037.2.083088

حجر زراعي

هل يقف عجز سياسات الحجر الزراعي في منطقة الشرق الأدنى وشمال إفريقيا وراء تفاقم وانتشار سوسة النخيل الحمراء *Rhynchophorus ferrugineus*؟. ساراث بابو بالاجي وجو رومينو فاليرو (الهند). الصفحات 89-100
http://dx.doi.org/10.22268/AJPP-037.2.089100

أعداء طبيعية

***Billaea rhynchophorae*، متطفل على سوسة النخيل بإمكانات عالية.** برن هاردلور، ألدو هيرمن غويريرو سوليز، خوان بيال ومولينا (كولومبيا والبرازيل). الصفحات 101-108
http://dx.doi.org/10.22268/AJPP-037.2.101108

مكافحة

الحلقة المفقودة والدروس الرئيسة للثلاثين سنة من الكفاح إزاء سوسة النخيل الحمراء. ميشيل فيري (إسبانيا). الصفحات 109-118
http://dx.doi.org/10.22268/AJPP-037.2.109118

دراسات للمعاملات الحية لمكافحة سوسة النخيل الحمراء *Rhynchophorus ferrugineus* Olivier في نخيل التمر باستخدام تقنية مبتكرة للتدخين. صلاح لبلاع وجو رومينو فاليرو (المملكة العربية السعودية والهند). الصفحات 119-123
http://dx.doi.org/10.22268/AJPP-037.2.119123

تقنية حقن بسيطة ومنخفضة التكلفة وتؤمن حماية فعالة لنخيل الزينة إزاء سوسة النخيل الحمراء خلال سنةٍ كاملة. سوزي غومز وميشيل فيري (إسبانيا). الصفحات 124-129
http://dx.doi.org/10.22268/AJPP-037.2.124129

الكشف المبكر والمكافحة الوقائية لسوسة النخيل الحمراء *Rhynchophorus ferrugineus* (عائلة السوس، رتبة غمديات الأجنحة): قصة نجاح في البرازيل. ف.أ. لطبون، ج. ب. ميفيدو، أ.ج.س. تالا، ح. ف. والرت، اي. التيرزا، أ. أيفيل، أ. ر. غويريس ليلي، ب. لور و ف. ب. روسيلي (البرازيل، كولومبيا وإيطاليا). الصفحات 130-135
http://dx.doi.org/10.22268/AJPP-037.2.130135

دراسات لتقنيات تعتمد على كيميائيات الاتصال والانتقاء لتطبيقها بصورة لمكافحة سوسة النخيل الحمراء *Rhynchophorus ferrugineus* Olivier استناداً لتجارب في المملكة العربية السعودية والهند. جو رومينو فاليرو، عبدالمنعم الشواف، حمدتو عبدالله فرا الجشفي وسيريبابي راليكار (الهند والمملكة العربية السعودية). الصفحات 136-142
http://dx.doi.org/10.22268/AJPP-037.2.136142

التسخين بالموجات الدقيقة: حلٌّ واعد وملائم بيئياً للحدّ من انتشار سوسة النخيل الحمراء. ر. ماسا، ج. بيراليو، م. د. ميغليور، ديبيشري ا، ف. شيتينو، ر. جريفو، م. ماترو، ك. باوور، ب. مياوفلين و إ. كلوبي (إيطاليا). الصفحات 143-148
http://dx.doi.org/10.22268/AJPP-037.2.143148

كفاءة الطعوم الغذائية والمواد الجاذبة الصناعية ونوع المصيدة في اصطياد سوسة النخيل الحمراء باستخدام مصائد الفيرمونات التجميعية ضمن مزارع النخيل في الإسماعيلية، مصر. عبدالمنعم البنا، محمد كمال عباس، طه عادل وتامر سهل محمد إبراهيم (مصر). الصفحات 149-150
http://dx.doi.org/10.22268/AJPP-037.2.149150

سياسات لمكافحة سوسة النخيل الحمراء استناداً لتوصيات اجتماع روما. شوقي الدبعي (إيطاليا). الصفحات 151-152
http://dx.doi.org/10.22268/AJPP-037.2.151152

قضايا جدلية حول سوسة النخيل الحمراء. حسين حيي آل عائض وأحمد محمد الجهر (المملكة العربية السعودية). الصفحات 153-155
http://dx.doi.org/10.22268/AJPP-037.2.153155

تطوير سلسلة قيمة التمور ومكافحة سوسة النخيل الحمراء في مصر. محمد كمال عباس وثائر ياسين (مصر). الصفحات 156-157
http://dx.doi.org/10.22268/AJPP-037.2.156157

نشر التدابير الوقائية في الحدّ من الإصابة بسوسة النخيل الحمراء في النخيل. محمد كمال عباس (مصر). الصفحات 158-158
http://dx.doi.org/10.22268/AJPP-037.2.158158

مكافحة متكاملة

أهمية العمليات الزراعية في الحدّ من إصابة نخيل التمر بسوسة النخيل الحمراء. محمد بن ناصر الحسني (سلطنة عمان). الصفحات 159-162
http://dx.doi.org/10.22268/AJPP-037.2.159162

إدارة سوسة النخيل الحمراء *Rhynchophorus ferrugineus* Olivier باتّباع خيارات مستدامة في المملكة العربية السعودية. محمد علي بوب (المملكة العربية السعودية). الصفحات 163-169
http://dx.doi.org/10.22268/AJPP-037.2.163169

لمحة عامة حول الثغرات والتحديات وآفاق إدارة سوسة النخيل الحمراء. جو روميو فاليرو، ميشيل فيري، ثائر ياسين وشوقي الدبعي (الفاو، مصر وإيطاليا). الصفحات 170-177
http://dx.doi.org/10.22268/AJPP-037.2.170177

سوسة النخيل الحمراء *Rhynchophorus ferrugineus* Olivier: آخر التطورات. فرانسيسكو غونزالز، سيادة خراط، كارلوس رودريغوز، كارولينا كالفو وكان أو شلجر (كوستاريكا وتونس). الصفحات 178-187
http://dx.doi.org/10.22268/AJPP-037.2.178187

استراتيجية فعّالة لتحقيق انخفاض في أعداد سوسة النخيل الحمراء على نحوٍ سريع جداً في منطقة ما مزروعة بنخيل الزينة. ميشيل فيري، رافائيل كوزن، دانييل كابلوندا وفريدي ليكفيرو (إسبانيا وفرنسا). الصفحات 188-197
http://dx.doi.org/10.22268/AJPP-037.2.188197

مكافحة حيوية

تأثير فطور ممرضة للحشرات في موت وخصوبة سوسة النخيل الحمراء وكفاءتها التناسلية. وكيل وقاص، محمد مظفر منصوري وهريش غولزار (باكستان). الصفحات 198-199
http://dx.doi.org/10.22268/AJPP-037.2.198199

هل يعدّ استخدام فطور ممرضة للحشرات خياراً قابلاً للتطبيق لمكافحة سوسة النخيل الحمراء؟. مصطفى البوحسيني، عبد النور الصرتي يوسي وظلال قدور (المغرب وسورية). الصفحات 200-202
http://dx.doi.org/10.22268/AJPP-037.2.200202

تنبؤ

رصد سوسة النخيل الحمراء ونظام الإنذار المبكّر. كيث كيسمان (إيطاليا). الصفحات 203-204
http://dx.doi.org/10.22268/AJPP-037.2.203204

الأثر الاقتصادي

الأثر الاقتصادي لسوسة النخيل الحمراء في مصر. محمد كمال عباس (مصر). الصفحات 205-205
http://dx.doi.org/10.22268/AJPP-037.2.205205

Automatic localization of phoenix by satellite image analysis

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Abstract

Cousin, R. and M. Ferry. 2019. Automatic localization of phoenix by satellite image analysis. Arab Journal of Plant Protection, 37(2): 83-88.

The Red palm weevil (RPW) *Rhynchophorus ferrugineus* is becoming one of the deadliest pests of the palms in the world. In order to effectively implement a RPW control programme to achieve rapid regression of this pest, it is necessary to have GPS coordinates of each palm present on the control perimeter. This location makes it possible to establish maps and databases which are essential for organizing, at the local and national level, the implementation and permanent monitoring of control measures. It is difficult, time-consuming and expensive to locate palms by visually exploring the entire perimeter from the ground. In the zone of regular plantations, this work can be processed but it becomes extremely heavy in the traditional oasis like in urban environment where the distribution of the palms is very irregular. With advances in satellite imagery, it is possible to acquire high quality images at very short intervals of time from a standard format for a large part of the earth. Combined with the progress of machine learning, particularly deep learning, this amount of data is able to feed a robust model. It would allow to automate the detection of palms at large scale and monitor their evolution at very short intervals, which in the fight against RPW is valuable information. This first work wants to test the interest in this solution. We build and train a convolution neural network in order to find two species of palms *Phoenix canariensis* and *Phoenix dactylifera* (C&D) in a very heterogeneous area of 100 km². Our model evaluation shows that 1/5 of the objects found are false positive and more than 2/3 of C&D are perfectly localized. These first results could be improved greatly by implementing a more robust algorithm using more data and using larger colour spectrum (as near infra-red). The question of the infested palms detection using satellite imagery and machine learning stays open.

Keywords: *Rhynchophorus ferrugineus,* remote sensing, machine learning, convolution neural network, vision.

Introduction

The red palm weevil (RPW) *Rhynchophorus ferrugineus* is one of the deadliest pests of the palms in the world (FAO 2017).

When a new infested palms is found or when a RPW is caught for the first time in a trap far from any known infested palms, it is necessary to implement immediately a contingency plan after delimitation of the potentially infested area (Figure 1). This plan must include in the delimited area the following activities (Ferry et Aldobai, 2017): location of all the palms owners to alert them; inspection of all the palms to locate the palm at the origin of the new infestation; immediate sanitation or eradication of the infested palms; preventive treatments on all the palms; collocation of traps for mass trapping. The awareness of the palms owners and their training will, generally be implemented. The technical activities will be maintained till no more detection of infested palms and no more captures. The efficiency of the plan will be controlled by following permanently the evolution of the number of new infested palms and of the captures in the traps.

Such contingency plan must be implemented in all the infested areas at the local, regional and national levels. At these different scales, it is necessary to have the geolocation of all the palms. This geolocation and, consequently the information of the number of palms at each scale, will permit first to establish the programme to obtain the rapid decline of the RPW and the means need to be to dedicated for it. Then it will allow management and control of the programme and all the components of the IPM strategy with the assistance of GIS (Ferry, 2017). As emphasized by Fajardo during the Rome meeting (Fajardo, 2017), the success of the eradication programme in the Canary Islands would not have been possible without the assistance of GIS for the management of the action plan (Fajardo, 2017).

The information on the geolocation of the palms is usually not available. The geolocation of the palms by field survey constitutes an important work that require human resources, equipment and time, when action has to initiated as soon as possible. As in most of the countries, the epidemic today is very rapid, the apparition and the extension of a great number of outbreaks imply to locate the palms very quickly and on an increasing surface area. Furthermore, in many places, like the traditional oasis or the cities, the environment is very heterogeneous, therefore the localization of the palms is very complicated.

Satellite imagery continues to progress rapidly. It exists through a wide range of providers, with different spectra and resolutions for multiple usages. For example: Copernicus (European Space Agency) offers free and open source data. The two satellites Sentinel-2A (launched in 2015) and Sentinel-2B (launched in 2017) provide images of the Earth every 5 days in 13 spectral bands with a resolution of 10 to 60 m. DigitalGlobe (American company) markets high resolution images. One of its WorldView-3 satellites (launched in 2014) provides images up to 30 cm per pixel for the panchromatic band.

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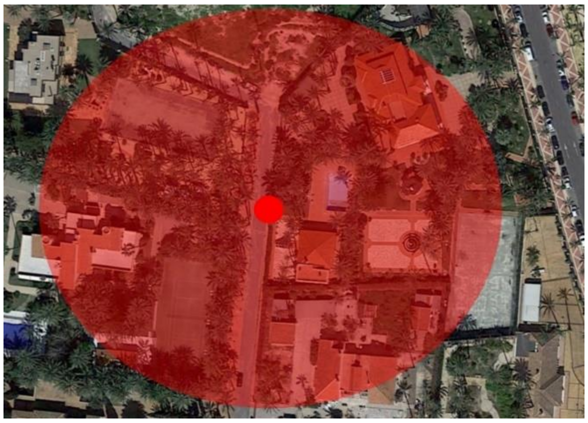

Figure 1. Illustration of the perimeter of control around infested palm tree.

At this level of resolution, it is possible to recognize by visual observation of the images, the palms with a good degree of certainty. Nevertheless, for large areas, such method of detection would represent very heavy task and the risk of error would become increasingly important.

Research has already been done using satellite images in order to automate the mapping of palm groves and the estimation of the number of palms. The analysis of the images and the contextual classification make it possible to estimate the number of the date palms with good precision using the data of WorldView 2. (Labrador-García *et al.,* 2013).

Machine learning has achieved important progress these last years. Particularly for object detection and image classification. When the data are of sufficient quality and number, it is possible to train a model with numerous parameters such as deep convolution neural networks (deep CNN) (Krizhevsky, 2012; Simonyan, 2014). These types of classifier are able to model complex problems in which they perform better than the other approaches (LeCun, 2015).

This deep learning approach was used on satellite imagery and has already demonstrated its ability to detect and localize oil palms under homogeneous and aligned planting conditions (Li *et al.,* 2016 and Santoso, 2016). It remains to test deep learning approach on more heterogeneous areas, such as in oases and urban areas, where RPW is more difficult to detect and monitor. It is in this sense that we conducted this first study to test the effectiveness of palms detection on satellite images.

Adult weevils in the test plantations

Pheromone trap densities in area-wide RPW-IPM programs range from one to 10 traps per hectare (Faleiro *et al.,* 2011; Oehlschlager 2006; Soroker *et al.,* 2005). However, increasing the trap density is often not possible due to the periodic servicing (change of food bait and water), necessary to sustain the trapping efficiency. In this context, the 'trap and bait free' A&K option could significantly augment the mass trapping programme of RPW by killing the emerging adult weevil population in the field. A&K technology can successfully eliminate adult RPW population. The technology serves as an excellent tool to manage RPW population where infestations are high, or in plantations that are inaccessible and neglected and could significantly strengthen the on-going pheromone trap based RPW-IPM strategy particularly in plantations where the pheromone trap density has to be increased to effectively mass trap the adult population. The cost involved in the periodic servicing associated with the traditional food-baited pheromone traps is effectively eliminated with this 'bait and trap free' technique of controlling the adult RPW population in the field. However, a minimum of one food baited pheromone trap/ha is required to be maintained in an area-wide RPW control programme to gauge weevil activity in the field. Furthermore, A&K has the potential to do away with the need to take up routine periodic preventive insecticide sprays. The technique has been used in RPW-IPM programs in date palm, the canary palm and coconut in Mauritania, Abkhazia in the Republic of Georgia and Malaysia, respectively.

All safety precautions (wearing of gloves, mask, foot wear, etc.) need to be complied with while applying RPW A&K formulation in the field. In case of allergic reaction or coming in direct contact with the product, further application should be stopped, immediate medical assistance sought and the manufacturer contacted.

The Electrap™ is an efficient service free semiochemical mediated technology against RPW and can be incorporated in RPW-IPM programs. However, known RPW repellents need further testing to be incorporated in an RPW-IPM program involving a push-pull strategy.

Materials and Methods

Area of interest

We focused our attention on a region (Figure 2) of Nice of 100 km² (south-east of France: N43°42'41.338" - E7°15'56.854"). Located between sea and mountains, this area of 350,000 inhabitants is a very heterogeneous area with significant variability of objects. Human construction and vegetation mix. Sparse areas bring out an important plant diversity. There is also the presence of a forest. Different species of palms are present, mainly for ornamental purposes.

Figure 2. Area of interest

We decided to study in the first place the location of C&D. Note the important presence of another palm specie, the Washingtonia. In 2014, we estimated approximately 30,000 of C&D in the area. Since then, a major RPW infestation has killed a large part of the *Phoenix canariensis* (Figure 3 and 4) Images and Data (http://propalmes83.com/index.php/actualites2/144-hecatombe-des-palmiers-a-nice-le-procureur-mene-l-enquete)

Figure 3. satellite image of palms - Hyères (France) 2007

Figure 4. Satellite images of palms Hyères (France) 2018

For this first test, we used Google Maps api images dated 2014, which are free (in limited number and condition), of very high quality in our area of interest (<30 cm per pixel), in natural colour RGB (8 bytes), and ready to use (there is no need to apply atmospheric correction or image preprocessing). We aggregated 55,000 square images 600 pixels wide to cover the entire area (100 km²).

Filter

To reduce the cost of treatment, we eliminated obvious non-vegetation areas (such as the sea and large buildings) by applying a simple colour test.

Labelling and set training

We decided to find C&D palms in this area. For this purpose, we built a simple GIS browser application (using Node.js and leaflet) to label images (Figure 5). We visually detect and manually selected: (i) 1000 images centred on a palm (a *Phoenix canariensis* or a *Phoenix dactylifera*), and (ii) 3000 images of various other objects (including other palms species and containing partial C&D). For a simple implementation, each image had the same square size of 80 pixel width (around 2.4 m width at ground level). Then, we artificially enlarged our training set by 90° rotations (that multiplies the size of sample by 4) and adding a random correction of the brightness (that multiplies the size of sample by 2). So we have 32,000 images to train and test our model.

Figure 5. labelled images: C&D and other objects

Model and architecture

We built a convolution neural network classifier (Figure 6) with Python and Keras framework. Constituted by: (i) in entry, our 19200 dimension image (80 pixels times 80 pixels times 3 colours), (ii) 8 layers of convolution 2d, (5 by 5 kernel) connected with relu activation, (iii) 1 max pooling layer, (iv) 1 full layer with 120 neurons and relu activation, (v) 1 sigmoid activation output.

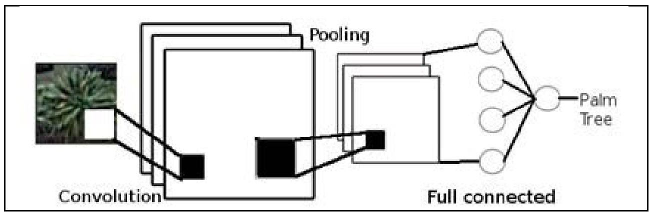

Figure 6. Convolution neural network

Training and testing

Using our labelled data, we trained our model with binary cross entropy loss and optimizer adam. We used cross validation, training with 90% of our data and testing with 10%. Stochastic gradient (mini batch) and 2000 epochs allows us to have an F1 score better than 90% on the test set.

Application to the whole area

We used our trained model over the whole area using sliding window (Figure 7) (by moving our slider by 5 pixels). At every stage we predicted with our model the confidence of detecting a C&D palm. We only hold the prediction with a confidence greater than 65%. To avoid overlapping results, we used non-maximal deletion to delete multiple positives from the same object. We recorded the positive results in a database (we used mongodb) with the location (wgs84 coordinates), the confidence index and the number of overlapping images discarded.

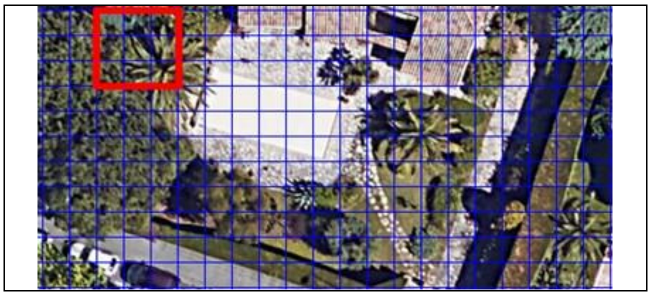

Figure 7. Sliding window

Results

We located around 20,000 palms in the whole area (Figure 8). In order to evaluate our approach, we manually controlled the results in a smaller but representative area (Figure 9) (around 4 km²).

In this area we manually identified and counted around 3000 C&D. For its part, our model located around 2500 objects, 2000 are C&D, 500 are false positive (non *Phoenix canariensis* and non *Phoenix dactylifera*). Our final metrics had a precision of 79% (Figure 10), recall 68% (Figure 11), F1 score 73% (Figure 12). That means our model located more than 2/3 of the C&D of the area. And around 1/5 of object found were false positive (non *Phoenix canariensis* and non *Phoenix dactylifera*). This evaluation of the results gave an order of magnitude but the exact figures must be taken with care. The control of palms in the area has been done by the human eye, and despite our greater attention, we have to consider a margin of error.

Figure 8. Objects found by the model

We also reviewed the results one by one. We observed that sometimes the algorithm was very efficient, it is able to find a *Phoenix canariensis* hidden by another tree or in the shadow of a building. But at other times, it totally misses its objective, some shapes found do not look at all like palms. This error can be explained by the classification principle used here, which is one against the other. Which means that the model tried to learn the shapes and colours of specific palms (C&D), against the shapes and colours of all the other objects. The second group had much more variability. Probably some objects of the second group slipped into the first group because they were not sufficiently represented in the learning dataset. Likewise, the 1,000 C&D images used for training were selected "at random" by human. We unfortunately tended to select a subsample of the diversity. This significant bias may explain why the model omitted one-third of the objects of interest. It is important to note that the number of Washingtonia found was low, which means that the model was able to understand the difference between different palm species.

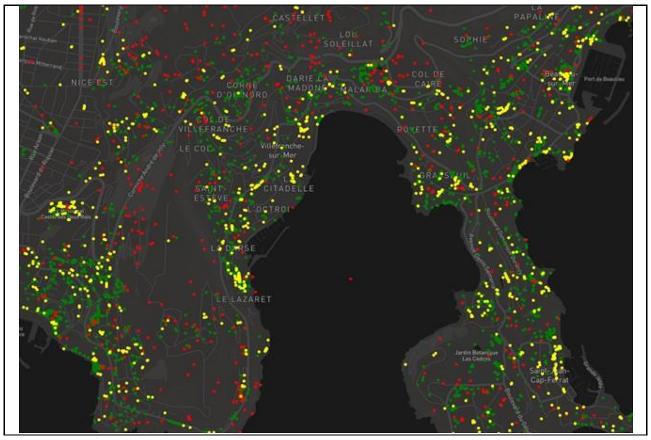

Figure 9. Results evaluation (green = True positive, red = False positive, yellow = False negative)

$$\text{Precision} = \frac{\textit{True Positive}}{\textit{True Positive} + \textit{False Positive}}$$

Figure 10. Precision metric formula

$$\text{Recall} = \frac{\textit{True Positive}}{\textit{True Positive} + \textit{False Negative}}$$

Figure 11. Recall metric formula

$$\text{F1} = 2 \times \frac{\textit{Precision} * \textit{Recall}}{\textit{Precision} + \textit{Recall}}$$

Figure 12. F1 score metric formula

Discussion

The objective of this work is to show the interest of using machine learning (deep learning) and satellite imagery to map palms localization at large scale. Obtaining the exact location of the palms is of great importance for the RPW control programmes. This first results obtained by a simple convolution neural network can be improved by different ways.

Without the need to have 50 million images like the ImageNet database (Krizhevsky, 2012), larger sample of data would represent better the diversity of palms and objects, and we would be able to build deeper architecture and train more robust model like the VGG-16 architecture (Simonyan, 2014). Also, the variability of the objects of non interest is very high, it could be easier for the model to learn with multi class than binary class.

Another improvement would be to change the following point: we always used the same size of images, we used sliding windows, and we removed overlapping result. This technique is easy to train but very expensive in calculation. CNN caffe implementation (Yangqing, 2014) or real time detection object detection algorithm (Redmon, 2016) could optimize our method.

It is also interesting to notice that remote sensing, is used to extract more complex information than just detection. Particularly with better resolution imagery obtained by aircraft or UAV, water status of palms for example was studied (Cohen, 2012). Likewise, CNN detection of the palms Raphia in a very dense environment provides better accuracy than human eye (Viennois, 2018). But early RPW detection remains difficult even with UAV. With UAV, interesting results have been obtained, but the infested palms were detected at a late stage (Golomb, 2015). It is not surprising as RPW attack date palms at the trunk level which is different from what occur with the *Phoenix canarienis*, which is infested at the leaves level. In that case, physical and physiological damages caused by the larvae appear on the foliage that is photographed by satellite or UAV. For the date palms, it is necessary to know that the damages created in the trunk, lead to physiological disorders detectable at the foliage level. This difficulty is well illustrated by the interesting results obtained in the evaluation of the importance of Dubas Bug attacks on date palms by satellite imageries analysis (Al Shidi, 2019). The attack was detectable because the Dubas bug creates direct and indirect symptoms on the foliage. Nevertheless, for the RPW on C&D late detection would be also very useful, especially in places where the observations of the palms is weak or null.

Conclusion

This palms detection research using convolution neural networks and satellite imagery in heterogeneous urban area gives encouraging preliminary results. Our evaluation model showed that only 1/5 of the objects found were false positive and more than 2/3 of C&D were located. Furthermore, various possibilities are available to improve the method: increasing the number of data in order to build and train deeper model. Also, it is possible to enrich the image with other pertinent information provided by satellites (like near infra-red).

It would be interesting to integrate to future research palms infested with RPW, taking into consideration the level of infestation and the difference between date palm and *Phoenix canarienisis*.

الملخص

كوزان، رفائيل وميشيل فيري. 2019. التحديد التلقائي لمواقع أشجار النخيل بتحليل الصور الفضائية. مجلة وقاية النبات العربية، 37(2): 83-88.

لقد بيّنت سوسة النخيل الحمراء *Rhynchophorus ferrugineus* واحدةً من أكثر الآفات تهديداً لأشجار النخيل في العالم. ويفرض تنفيذ برنامج لمكافحة سوسة النخيل الحمراء فعالية تحقيق الحراسة على هذه الآفة، ولذلك من الضروري أن يكون لك إحداثيات جغرافية (الموقع GPS) لكل نخلة موجودة ضمن حدود منطقة المكافحة. تحديد هذا الموقع يتيح إمكانية تأسيس خرائط وقواعد بيانات تعدّ ضرورية للتنظيم على المستويين المحلي والوطني وكذلك للتنفيذ والمراقبة لاستراتيجية المكافحة. كما تعدّ عملية تحديد موقع أشجار النخيل ضمن كامل المحيط بالاعتماد على الكشف البصري من على سطح الأرض أمراً صعباً ومكلفاً ويستغرق وقتاً طويلاً؛ إذ يمكن إنجاز مثل هذا الإجراء ضمن المزارع المنتظمة، إلاّ أنه يصبح ضرورياً جداً في الواحات التقليدية وكذلك الموجودة في البيئة الحضرية والتي يكون توزّع النخيل فيها غير منتظم إلى حدٍ بعيد. وعلى ضوء التقدّم في التصوير الفضائي (صور الأقمار الصناعية) فقد بات بالإمكان الحصول على صورٍ ذات جودةٍ عالية لجزء كبير من الأرض خلال فواصل زمنية متقاربة وبتكاليف معقولة. وبالتضافر مع التقدّم في مجال التعلّم الآلي وخصوصاً التعمّق فيه، فإنّ قدرات الحاسوب تكون قادرةً على التعرف على نموذج قوي، ويتيح إمكانية الكشف التلقائي عن أشجار النخيل على نطاقٍ واسع، ورصد تطوّرها خلال فتراتٍ زمنية قصيرة جداً؛ وهذا ما يعتبر معلومات قيّمة في إطار التصدّي لسوسة النخيل الحمراء. ويتيح هذا العمل لكي يطبّق للمرّة الأولى إلى اختبار مدى الاهتمام بهذا الحلّ. أنشأنا ودرّبنا شبكة عصبونية تلافيفية في محاولةٍ لالتقاط نوعين من النخيل هما: نخيل الزينة *Phoenix canariensis* ونخيل التمور (C&D) *Phoenix dactylifera* ضمن منطقة متحضّرة أجناساً متغايرةً إلى حدٍ كبير بمساحة تبلغ 100 كم². أظهر تقييم النموذج بأنّ 5/1 من المخرجات كانت موجبةً ولكنها غير حقيقية، وأنّ ما يزيد عن 3/2 من نوعي النخيل (C&D) قد تمّ تحديد موقعها بدقّة. ويمكن تحسين هذه النتائج الأولية على نحوٍ كبير من خلال تضمين خوارزمية أكثر عمقاً وبيانات أضخم وطيفٍ أكبر (مثل الأشعة تحت الحمراء القريبة). ويبقى السؤال قائماً حول تحديد أشجار النخيل المصابة باستخدام التصوير الفضائي والتعلّم الآلي.

كلمات مفتاحية: *Rhynchophorus ferrugineus*، الاستشعار عن بعد، التعلّم الآلي، شبكة عصبونية تلافيفية، رؤية.

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Is policy paralysis on quarantine issues in the Near East and North Africa region leading to the buildup and spread of red palm weevil, *Rhynchophorus ferrugineus*?

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Abstract

Balijepalli, S.B. and J.R. Faleiro. 2019. Is policy paralysis on quarantine issues in the Near East and North Africa region leading to the buildup and spread of red palm weevil, *Rhynchophorus ferrugineus*?. Arab Journal of Plant Protection, 37(2): 89-100.

The red palm weevil (RPW) is now a global threat, demanding a global strategy for its control and eventual eradication. In North Africa, RPW has been reported from all the countries except Algeria leaving several queries as to why this pest did not reach there. Enforcement of strict quarantine measures in the five Maghreb countries of Algeria, Morocco, Tunisia, Libya and Mauritania kept the weevil at bay until 2008, but the region is today riddled with this dreaded pest with the exception of Algeria. There is plenty of evidence to suggest that strict regulatory regimes can restrict the spread and eventually eradicate the pest. The RPW-IPM program of Canary Islands in Spain where the RPW was effectively eradicated with no reports of weevil captures since 2016 is a classic example. Likewise, in Mauritania and Morocco quarantine laws did prevent the spread of the weevil, restricting it to the original foci of infestation. Ineffective quarantine regimes coupled with weak enforcement and difficulties in early detection of infested plants contributed to the rapid spread of RPW. Country reports on variety of issues right from the status, challenges and recommendations with respect to RPW control in Egypt, Iran, Iraq, Libya, Morocco, Mauritania, Oman, Palestine, Qatar, Saudi Arabia, Tunisia and Yemen reveal that the weevil arrived in these countries through infested date palm offshoots, ornamental palms or hitch hiking on moving vehicles. Although quarantine laws/decrees/ordinances existed in most countries to prevent the movement of plants however, ineffective and poor enforcement and implementation has resulted in the rapid spread of the pest which can be attributed to policy paralysis. Focus must therefore be shifted to devising mechanisms for effective decision making in implementing phytosanitary regulations to stop the spread of RPW both within national borders and also across international boundaries. Based on recent experiences in Saudi Arabia, recommendations drafted during the last mission in 2018 on phytosanitation and quarantine protocols for the Kingdom are presented here that could serve as guidelines on quarantine issues against RPW for the region. Specific regulations and measures are sought to be developed with in the phytosanitary legislation especially with regard to palm tree inspections, removal of infested palms, movement of palms and treatment protocols. Enforcement of harmonized plant quarantine protocols for phytosanitary treatments and specifications of planting material produced through certified palm nurseries on the basis of IPPC standards (ISPM 36) besides establishment of tissue culture laboratories with standard production protocols to facilitate RPW free planting material throughout the region are presented in this article.

Keywords: *Rhynchophorus ferrugineus,* red palm weevil, quarantine protocols, phytosanitation, policy regulations, policy paralysis, NENA, registered nurseries, certified offshoots, tissue culture plants.

Introduction

The red palm weevil (RPW), *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae) is a key pest of palms originating from South and South East Asian Countries that has significantly expanded its geographical and host range during the last three decades. In the Near East, RPW is causing wide spread damage to date palm, *Phoenix dactylifera* L., having both agricultural impacts on the palm production, which has negative repercussions on the livelihoods of farmers and environmental impacts. In North Africa, except in Algeria, RPW is spreading its tentacles very fast though few years ago it was only thriving in few limited spots, only on the Canary Island palm *P. canariensis*. Even when these spots are located on the Mediterranean coast, they represent a serious threat for the Southern oasis.

RPW destroys palm trees by eating them from the inside, invaded rapidly from South East Asia in to more than 60 countries during the last three decades. It threatens date and coconut palms, as well as ornamentals. Factors contributing to the spread have been lack of healthy certified planting material, late detection of infested palms because of insufficient inspections, lack of engagement with date and coconut farmers, improper assessment of the risks, ineffective natural enemies of the pest, difficulties in managing mass trappings across large oases networks, lax quarantine, improper disposal of infested trees, and the difficulty in controlling the pest in private homes or small family gardens. All over the NENA region and other Mediterranean countries, IPPC standards, policy regulations and legislations are either not functioning with harmony or there are no proper enforcing mechanisms in some countries culminating into spread of this insect to dangerous proportions. There is an overall policy paralysis, calling for attention of the decision makers for policy formulation and enforcement in some regions afresh and its activation wherever it is sluggish on priority in NENA region (Figure 1). In a nutshell, the RPW in the recent past turned to a global threat demanding a global strategy to eradicate it, as declared by FAO Director-General José Graziano da Silva in a recent strategic scientific consultative meeting to combat the RPW menace. The message emanating from the scientific

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consultative meeting is a positive one: The Red Palm Weevil can be controlled and defeated.

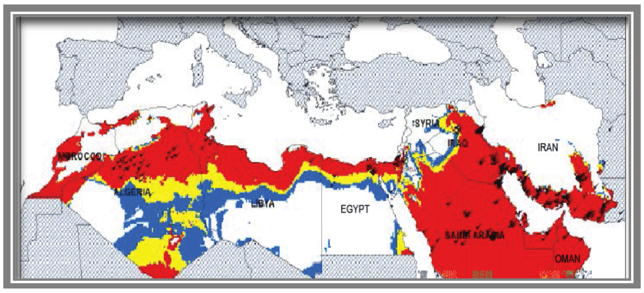

Figure 1. Red palm weevil conquering most territories of the Near East and North African region

Abraham *et al.* (1998) highlighted the importance of implementing strict quarantine regimes as a component of the *R. ferrugineus* control strategy. Transport of date palm offshoots for date farming and bigger date palms for landscape gardening often resulted in this cryptic pest moving rapidly to new regions or also in and around plantations where the pest is already controlled, resulting in new foci of *R. ferrugineus*. Experiences from the Gulf region in the Middle-East and the Mediterranean countries have shown that RPW had spread rapidly through infested planting material transported mainly for ornamental purposes and also date palm farming (Faleiro *et al.*, 2012). Several date palm producing countries have legal decrees restricting/banning the movement of such material. Very often implementing the decree becomes difficult especially due to the lack of quarantine protocols for treatment of offshoots/palms and subsequent certification of the material as "pest-free". In Europe the palm nursery industry is strictly regulated to supervise the movement of palms (EPPO 2008). In Saudi Arabia, Al-Shawaf *et al.* (2013) developed a quarantine protocol of dipping date palm offshoots in 0.004% Fipronil for 30 minutes to destroy all stages of the pest. Consultation in the form of national and regional cooperation among date producing countries is essential to deploy and implement uniform quarantine regimes to control this key pest of date palm in the entire NENA region.

Systematic approach to deal with this pest yielded success, as in case of the Canary Islands. The pest was detected in 2005 and caused destruction of thousands of canary palm during the following years. A systematic policy declaration and enforcement with very strict vigil brought down the insect pressure tremendously by 2015 and the islands were declared RPW free by May 2016 (Fajardo, 2017). Implementing a coordinated strategy that included tight monitoring controls, healthy planting material and the removal of all infested trees. In Mauritania, detection of the pest in an oasis triggered quick action by the Government with the support of FAO to implement an integrated pest management strategy that had farmers and farmer cooperatives at the core. The pest has been successfully contained to the original infestation area, without any outbreaks from May 2016.

The new framework (RPW Expert Team, 2017) aims to provide technical assistance and guidance for improving national control programs as well as a platform for inter-regional cooperation and coordination. It was produced by an international team of Red Palm Weevil experts from various countries and organizations with the support of FAO, CIHEAM and the Near East Plant Protection Organization (NEPPO) (FAO, 2017).

Just four palm species were affected by red palm weevil when studies were done in 1956, but now the pest attacks 40 palm species worldwide (Malumphy and Moran, 2009). The three most-affected species today are coconut palm, date palm and the tall ornamental Canary Island date palm.

Global Economic and Social Impact of RPW Infestations

The weevil, which has spread rapidly through the Middle East and North Africa in the last three decades, causes economic losses in millions of dollars annually through lost production and pest control. It attacks 40 palm species, the most affected being the coconut palm, date palm and the tall ornamental Canary Island date palm (Gibbins-Davis *et al.,* 2013).

Date palm represents a symbol of life in the Near East and North Africa (NENA) region and has a long heritage of sustaining human life in hot and infertile areas, where it is seen as a renewable natural resource. RPW has significant socio-economic impact on the date palm production sector and livelihoods of farmers in affected areas. In the Middle-East, RPW has been the most destructive insect pest of date palm and is designated as category-1 pest by FAO. The annual loss during 2009 in the Gulf region of the Middle-East due to removal of severely infested palms has been estimated to range from 1.74 to 8.69 million USD at 1 and 5% infestation, respectively. Recent reports indicate that in the Mediterranean region, palms worth up to 483 million Euros have been destroyed or infested, primarily by RPW. However, this figure remains a significant underestimate of the total economic value of affected palms because no study has accounted for all of the ecosystem services they provide. In the Spanish region of Murcia over 7 million Euros were spent on various measures to combat RPW mainly on the removal of infested palms. Between 2004 and 2009, in the autonomous community of Valencia around 20,000 palms, mostly *Phoenix canariensis,* were killed by RPW, where losses were estimated to be 16 million Euro (Faleiro *et al.,* 2012)

In recent years, *R. ferrugineus* has been the most destructive insect of palm plantations throughout the world (Bertone *et al.,* 2010), and FAO has designated it as category-1 pest on date palm in the Middle-East. Losses in global production of dates have been estimated at 30% due to the plant diseases and pests (FAOstat, 2013). The annual loss in the Gulf region of the Middle-East due to eradication of severely infested palms has been estimated to range from US$1.74 to 8.69 million at 1 and 5% infestation, respectively (El-Sabea *et al.,* 2009).

Red Palm Weevil Invasion

In a recent global conference, FAO head Jose Graziano da Silva said, “The red palm weevil has become a global threat and demands a global strategy to eradicate it.” Agricultural ministers have agreed on a plan to fight the red palm weevil which ravages coconut, date and oil palms, experts said describing it as “a global threat”. The red weevil, which has few natural enemies, has spread to more than 60 countries from the Caribbean to southern Europe, according to FAO which hosted a meeting of scientists, pest control experts, farmer representatives and government officials in Rome (RPW Expert Team, 2017).

Red palm weevil literally conquered the date palms in the Middle–Eastern and the Mediterranean region since 1985, its occurrence as a pest was reported from Ras–Al–Khaima in UAE (Zaid *et al.,* 2002), where it probably got introduced through infested planting material (ornamental palms) from South/South East Asia. Red palm weevil in Saudi Arabia, was first detected in an ornamental nursery in Al Qatif in early 1987, from where it spread to the entire Kingdom through date palm offshoots and also through bigger palms transported for ornamental purposes (Anonymous, 1998; RPW Red palm weevil website). It crossed the red sea in early 1990’s and was recorded in Egypt in 1992 and in Spain in 1995 (Barranco *et al.,* 1996; Cox, 1993). The entire Mediterranean basin is currently reporting RPW infestations mostly on *Phoenix canariensis* (Faleiro, 2006 and OJEU, 2008) (Table 1). Previous experiences suggest that shipments of ornamental palms without quarantine certification have contributed significantly to the spread of RPW (Faleiro, 2006 and Oehlschlager, 1994). The Maghreb region of North Africa is critically situated between several RPW infested countries including Egypt on the East, the Canary Islands on the West and European countries including Spain, Portugal, France and Italy in the North (RPW, Red Palm Weevil, http://www.redpalmweevil.com/). This region has around 12 million date palms in the susceptible age group of less than 20 years (Table 1) and several avenue plantings/nurseries of *P. canariensis* offering RPW an ideal agro-climatic zone to establish and spread in the region. It is relevant to point out that during 2 years (2008-2010), RPW was recorded in the Maghreb region (Tangier in Northern Morocco and Libya) (RPW, Red Palm Weevil, http://www.redpalmweevil.com/), the American continent (Dutch Antilles Island in the Caribbean), Laguna Beach area of Orange County, California, USA and Eastern Europe (Georgia) (RPW, Red Palm Weevil, http://www.redpalmweevil.com/). With regard to the Orange County report, lack of response by the weevil to the pheromone (ferrugineol) traps and limited spread of the weevil in the Laguna Beach area suggest that it may not be *Rhynchophorus ferrugineus*. However, all these reports are attributed to palms maintained (garden nurseries) or shipped for ornamental purposes. Reports from area-wide RPW-IPM programme in KSA indicated that 75% of the infested date palms are in the age group of 6 to 15 years (Anonymous, 1998; Oehlschlager, 1994). This is the age group of palms preferred for ornamental landscaping purposes as stated in the first report of RPW in the Caribbean Island of Curacao (Dutch Antilles) when date palms imported from Egypt for ornamental purposes (RPW First Report in the Caribbean ; RPW, Red Palm Weevil, http://www.redpalmweevil.com/). It is evident that the initial source of infestation occurred in most of the countries through imports of palms for ornamental purposes which subsequently spread to date palm plantations (RPW, Red Palm Weevil, http://www.redpalmweevil.com/). Therefore, the Maghreb countries should impose a ban on the imports and regulate internal movement of palms for ornamental gardening. The pest was accidentally introduced into the territory of the European Union. Spain reported its presence in 1996 and this was followed by reports from Italy in 2004, Greece in 2005, Cyprus and France in 2006, Malta and Portugal in 2007, and Slovenia in 2009. Currently it is present in all Mediterranean Member States and Portugal (Faleiro *et al.,* 2012).

The Maghreb region of North Africa successfully avoided invasion by red palm weevil until 2008, when it was confirmed to be present in Morocco (Faleiro *et al.,* 2012). Its presence was subsequently confirmed in Libya in 2009 (Al-Eryan *et al.,* 2010), and in Dec 2011, despite laws established several decades earlier strictly forbidding the importation of live palms (EPPO 1999), red palm weevil was confirmed for the first time in Tunisia, in Carthage Township, Tunis (Chebbi, 2011). (Rugman-Jones *et al.,* 2017) reported invasion of Tunisian palms by RPW. Moreover, although red palm weevil is currently restricted to urban areas in Tunis, its establishment poses a major socio-economic threat to the date industry in the southern regions of the country. Tunisia is the biggest supplier of dates to the European Union (Ben-Amor *et al.,* 2015), and it is estimated that ~12% of Tunisians derive income from date production (Faleiro *et al.,* 2012). Although the RPW is reported from all over the Meghreb region of North Africa, it was not found in any of the official records in Algeria (Faleiro, 2012), and absence of RPW through surveys in Algeria was confirmed by datasheet records (CABI, 2018). Therefore, it is worth studying the case of Algeria and its regulations systematically. Quarantine measures or strict regulations through decrees were undertaken in Algeria strictly to eradicate the Bayoud disease (Nadia Bouguedoura, 2015) within the region. In early 1970s three million palms in Algeria and 10 million in Morocco were lost due to Bayoud disese caused by *Fusarium oxysporum* f. sp. *albedinis* (Foa) Malençon Snyd and Hans (Malençon, 1934). Strict policy enforcement by the Algerian government on movement of planting material to arrest the spread of Bayoud along with usage of tissue culture plants promoted by FAO both in Morocco and Algeria (Bouguedoura, 2015). Although RPW is a serious pest all around in Meghreb countries the weevil is yet to be reported from Algeria which is confirmed by CABI (Faleiro *et al.,* 2012; CABI, 2018; EPPO, 2014)

Outside the NENA region, the RPW appearance in Caucasus is also very alarming. It is very alarming to learn that during 2011-2017 an unusually high number of invasive pests new to European Russia were detected for the first time in Sochi on the Black Sea coast of the Caucasus (Bieńkowski *et al.,* 2018). The *Caucasus* is a region located between the Black and Caspian Seas. It consists of Southern Russia, Georgia, Armenia, and Azerbaijan. Known for its alpine terrain, the *Caucasus* is home to Mount Elbrus, the highest mountain peak in Europe, located on the Russo-Georgian border.

RPW, native to South-East Asia, began to spread in the 1980s outside its native range and now this invasive species has been established in the Middle East, North Africa, North America, countries of the Caribbean and South Europe (EPPO, 2017). It was added to the EPPO A2 list in 2006 and is regarded as a quarantine pest in several countries (EPPO, 2017). In 2009 *R. ferrugineus* was found in the Caucasus for the first time in Georgia (Pelikh, 2009). In 2012-2013 it was recorded in Sochi, where it mainly damages Phoenix canariensis and Washingtonia robusta (Karpun *et al.,* 2014).

Phytosanitary and Quarantine Regulations in NENA Region

Quarantine regulations in NENA region have been either non serious or policy protocols non-existent or were not enforced strictly based on international standards like IPPC. With the movement of planting material of dates and adult palms of ornamental palms freely across the borders in the NENA regions, the RPW moved without any quarantine challenge resulting in widespread distribution of the pest. RPW is a quarantine pest in the Near East and North Africa (NENA) countries, as well as in countries in Latin America, where it is the object of emergency measures in the European Union, and is considered a quarantine pest that should be regulated in EPPO countries as it is considered of limited distribution (A2 pest). Weak quarantine procedures and difficulties in the early detection of RPW-infested plant materials have contributed to its rapid spread. RPW has been spreading globally and has not been effectively managed in spite of several efforts and resources provided by countries and organizations. Extensive research has also been conducted on the management of RPW (RPW Expert Team, 2017).

With the advent of plant genetic resources collection, conservation and utilization, legal and regulatory phytosanitary systems have been developed in accordance with international directives and standards to regulate germplasm movement, exchange and quarantine of planting material, especially of clonally propagated fruit trees such as date palm (Noreiga *et al.,* 2012). As anticipated, the germplasm movement and exchange would accelerate as countries in the southern hemisphere were establishing large scale date palm plantations. The large volume of international germplasm transfer coupled with recent rapid advances in biotechnology called for development of date palm specific regulations for its phytosanitary safety during transfer and movement across the globe. The slow pace of policy development and the policy enforcement together could be defined as a policy paralysis which happened in the NENA region resulting in the spread of the invasive RPW pest. Therefore, even today, careful planning and enforcement of strategies designed for the arrest and spread of RPW across the NENA region would go a longway in reducing further spread and eventually eradicating the dreaded date palm enemy (RPW Expert Team, 2017).

Table 1. Red palm weevil appearance and spread in NENA region

Country	Year of Infestation	Reference
United Arab Emirates	1985	Zaid *et al.,* 2002
Qatar	1985	Zaid *et al.,* 2002
Kingdom of Saudi Arabia	1987	Oehlschlager, 1994
Iran	1990	RPW, Red Palm Weevil, http://www.redpalmweevil.com/
Kuwait/Behrain	1988-1993	RPW, Red Palm Weevil, http://www.redpalmweevil.com/
Egypt	1992	Cox, 1993
Jordan/Israel/Palestine	1999	Kehat, 1999
Spain	1995	Barranco *et al.,* 1996
Canary Islands	2006	EPPO, 2008
Greece	2005	EPPO Reporting Service, 2006 RPW, Red Palm Weevil, http://www.redpalmweevil.com/
France	2006	EPPO Reporting Service, 2006
Turkey	2005	RPW, Red Palm Weevil, http://www.redpalmweevil.com/
Malta	2007	Department of Plant Health, 2010
Cyprus	2006	RPW, Red Palm Weevil, http://www.redpalmweevil.com/
Morocco	2008	EPPO, 2010 RPW, Red Palm Weevil, http://www.redpalmweevil.com/
Georgia	2009	RPW, Red Palm Weevil, http://www.redpalmweevil.com/
Portugal	2006	RPW, Red Palm Weevil, http://www.redpalmweevil.com/ http://www.aambiental.org/palmweevil/
Libya	2009	RPW, Red Palm Weevil, http://www.redpalmweevil.com/
Tunisia	2011	Chebbi, 2011; EPPO, 2011

Benchmark Global Programmes

The author of this article having worked as quarantine expert for FAO, worked out and recommended in March 2018, a systematic approach including an incentive based phytosanitary regime for KSA. As a team player in the cluster of experts to combat RPW, long term strategies were drawn out for effective future management of RPW in the kingdom.

The benchmarks have been set up while dealing with the invasive species in countries like Saudi Arabia, Canary Islands, Mauritania, Morocco, Oman, Morocco and others (Table 2). These benchmarks and some good agricultural practices have been assessed for better understanding of the successful programmes and for adoption in KSA (Balijepalli, 2018a).

Looking at the variety of situations in the context of SPS of WTO *viz*., the European Union, the situation in Near East and North Africa is reviewed in this report in order to analyze and study the relevance and applicability of certain situations and provisions for adoptability with respect to the Kingdom of Saudi Arabia. There are specific examples such as Canary Islands, where a strong programme with adequate resources, systematic planning, good coordination and the involvement of all stakeholders, which lead to the control and eradication of RPW. In Mauritania, a swift reaction by the national authorities involving farmers and local communities, with the support of FAO, has also led to the rapid containment of the pest (RPW Expert Team, 2013).

Sanitary and Phytosanitary Measures

We need to understand SPS of WTO in the backdrop of international exchange of germplasm and commercial movement of agricultural commodities. This has immediate ramifications with respect to arresting or regulating the global movement of harmful pathogens and pests along with the food commodities. The WTO Agreement on Sanitary and Phytosanitary measures encourages member countries to use international standards, guidelines and recommendations where they exist. Members of the WTO can also use measures which result in higher standards, if there is scientific justification. They can also set higher standards based on appropriate assessment of risks so long as the approach is consistent and not arbitrary. Sanitary and phytosanitary measures aim to protect animal or plant life or health within the territory of the member country from risks arising from the entry, establishment or spread of pests, diseases and disease-causing organisms.

Within the policy framework and phytosanitary regulatory measures, FAO of the UN has in its Crop Production and Protection Division (AGP), a Trans-boundary Pests and Diseases Unit and Integrated Pest Management (IPM) Unit, for providing assured and quality technical assistance to member countries in areas associated with plant health. In addition, FAO hosts the secretariats of the international conventions and Commissions related to plant protection and pest management as the International Plant Protection Convention (IPPC) and its Commission on phytosanitary measures (CPM), which is the global treaty for the international harmonization of phytosanitary measures. IPPC is the organization that actually sets the standards in plant protection, quarantine and phytosanitary protocols based on regulations of planting material or agricultural commodities both for commercial and research exchange purposes for the benefit of all member countries of WTO. Therefore, the protocols required for pest risk analysis (PRA), establishment of certified nurseries, declaration of regulated non-quarantine pest, establishment of areas of low pest prevalence in the context of RPW are relevant. These very standards need to be applied towards developing policies and *sui generis* legislation in member countries for developing policy and regulations in quarantine and phytosanitation.

Saudi Arabia is a member of the World Organization for Animal Health (OIE), the Codex Alimentarius Commission, and a contracting party to the International Plant Protection Convention (IPPC). With regard to animals, plants, and their products, SPS measures are harmonized at the GCC level under the Veterinary Quarantine Law and the Plant Quarantine Law, and the corresponding Executive Regulations provide details of their implementation in Saudi Arabia. Saudi Arabia maintains bilateral arrangements on SPS matters with Belgium, Brazil, Canada, Denmark, Djibouti, Ethiopia, France, India, Ireland, the Netherlands, Kenya, Pakistan, Sudan, Turkey, the United Arab Emirates (Abu Dhabi), and the United States.

The Situation in European Union

The main legislative framework of the plant health regime in the EU is Council Directive 2000/29/EC of 8 May 2000 on protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community (European Commission, 2011).

Red palm weevil situation in European Union is by and large under check with the necessary amendments to the legislation and policy framework in 2007 and 2010. The RPW menace was successfully eradicated in areas like the Archipelago of Canary Islands where concerted efforts and systematic approach supported by the needful policy and legislation declared the island as completely free from the red palm weevil. The island of Gojo in Malta is now considered free of this organism. Also in Koper (the region of Slovania), the reports of few palms being infested and the successive efforts resulted in positively as there was no recurrence of the RPW since 2010.

The weevil having spread its tentacles in most palm growing areas has been on rampage with several countries like Cyprus, Greece, France, Italy, Malta, Portugal, Slovenia and Spain on record having initiated the fight against the spread of the weevil but without major success of eradication so far (Balijepalli, 2018a)

The Policy Adopted in European Union

It is quite relevant to highlight some of the European Union situations and protocols governing palm trade in Europe in the light of RPW menace in the Mediterranean basin countries that could be studied, modified and adopted to suit the needs of Kingdom of Saudi Arabia. RPW was added in 2005 to the EPPO A2 action list and endangered EPPO member countries are advised to regulate it as a quarantine pest. The RPW in European Union has been by and large successful in checking the spread culminating into large scale destruction of palms. As dwelled in the mission report (Balijepalli, 2018a), the policy interventions included mainly the following measures:

1. Delimitation of survey and demarcated areas
2. Three monthly official inspections
3. Annual crop declarations
4. Application of phytosanitary treatments
5. Registration of planting material movements
6. Use of plant passport to the trade of palms

The emergency measures, whenever red palm weevil strikes, include:

1. Categorisation of the red palm weevil: *Rhynchophorus ferrugineus* (Olivier).
2. Listing of susceptible hosts: 23 species and one genus of palms.
3. Specific requirements for the imports into the EU
4. Specific requirements for the internal movements within the EU.
5. Surveys to check for the presence or continued absence of red palm weevil.
6. Demarcation of areas in the community where red palm weevil is present.

Recommended Incentive-based Phytosanitary Regime for KSA

The mission undertaken by the quarantine experts recommended an incentive based phytosanitary regime in the Kingdom to deal with the RPW (Balijepalli, 2018a). The model developed for KSA which is incentive-based, especially with respect to making the healthy planting material available to the farmers, has been included and dealt with extensively (Table 3). The prerequisite studies for establishing the registered nurseries to supply certified planting material under the IPPC regime and its standards have been defined and protocols developed. The challenges identified and the policy paralysis existing throughout the NENA region have been discussed in the international meeting (Balijepalli, 2018b). There are some grey areas of crucial importance with respect to establishing demonstration farms to produce certified palm seedlings like identification of pest free areas (PFAs) and areas of low pest prevalence (ALPPs) etc. These are very significant in order to provide sources for offshoots or tissue culture plants to be further grown and developed under the supervision of trained inspectors and the inspection system, before supplying them to farmers. All this has to be undertaken following the best of standards established by IPPC (ISPM 36).

Significant contributions from the said mission are summarized as follows:

1. Assessing current internal quarantine system for palm seedlings and designed an improved system.
2. Working out an appropriate regulatory framework and incentives for certified palm seedlings. A protocol has been prepared on the basis of IPPC standard (ISPM 36) for implementation in the kingdom.
3. Support selection of appropriate mix of technologies for prevention and control of RPW insect based on benchmarking and good international practices.
4. Designed an integrated methodology for prevention and control of red palm weevil insect and its implementation in a pilot area.
5. Selection of a pilot area for testing and implementation of the strategy based on variety of technical and administrative inputs as team player.

The recommended crucial tasks or need to be undertaken in due course of time are:

1. Establishing demonstration farms that produce certified palm seedlings.
2. Train farmers and technicians and extension agents in selected technologies and practices.
3. Support training of farmers, technicians and extension agents in selected technologies and practices.
4. Legislative interventions with respect to amendments to quarantine law especially the incentives for compliance to regulations and to create sense of awareness of enforcement of regulations and punitive actions for violation by various stake holders.
5. All the partially undertaken or unfulfilled tasks are somewhere or the other related to the establishment of registered nurseries to produce certified date palm offshoots.

During this mission strategy for the production of certified offshoots has been developed. Also, necessary protocol for the production of certified offshoots has been developed to be synchronized with the planting material output from the tissue culture laboratories. The protocol broadly consists of the following.

a) Estimation of annual offshoot requirement in the kingdom.
b) Estimation of planting material already being produced by tissue culture.
c) Synchronization of activities of offshoot sourcing from recognized farms and sourcing of tissue culture plants based on scientific principles and established phytosanitary measures in accordance with the IPPC standards.
d) Protocols for sourcing, production, movement and distribution of offshoots / planting material in accordance with the IPPC (ISPM 36) standards.
e) Identifying pest free areas (ISPM 4) for sourcing offshoots and nursery establishment to produce certified offshoots.
f) Identifying areas of low pest prevalence and finding large farms (ISPM 22) for sourcing offshoots and nursery establishment to produce certified offshoots.
g) Finally establishing the demonstration farms as well as the nurseries producing certified date palm offshoots.
h) Training all stakeholders in the ministry, the internal quarantine team to carry out the necessary inspection and measures to ensure pest free offshoots and the

identified nursery owners on protocols and phytosanitary requirements.

i) Also a campaign to build awareness among the farmers to recognize the necessity of using only certified offshoots in the interest of the kingdom to get rid of the menace of red palm weevil.

Table 2. Bench Marking and Success criteria

Key Components	Saudi Arabia (Country report FAO)	Canary Islands (government source)	Morocco (Country report FAO)	Oman, 2015 (Country report)	Israel
Survey & infestation and number of palms in the area reports	Available from the year 1987 when first detected and number of palms known	Comprehensive data available from 2005 Eradicated in 2016	Detected for the first time in Morocco in December 2008 in Tangiers	First reported in 1993	First reported in 1999 and from 2000 to 2002 IPM was imposed in Jordan valley
what are the preventive measures/practices put in place to control RPW in the county	1. Inspection and treatment of palm injuries 2. No use of irrigation water on palm trunks. 3. Farmers' cooperation in good agricultural practices	Prohibition of susceptible palms less than 5cm diameter. Two preventive treatments a year	Preventive chemical, Pheromone trapping were by NPPO. Also removal of old palms	Management practices were effectively enforced.	Prophylactic insecticide and pheromone traps. Acoustic detectors and trained dogs used for detecting early
what extent are preventive measures/ practices applied by farmers/ stakeholders to control	30% of the farmers and stockholders	100%	Farmers applied curative measures.	65% of the farmers and stakeholders	
plant quarantine(phytosanitary) measures and regulations	Saudi Arabia bans the trading, transportation, import and export all kinds of date palms in infested areas applying the statutory procedures	Importers of palms much register with Directorate General. Permits required for plant movement	Import of adult palm trees banned in 2007. Orders in place 2009 control and surveillance	Royal decrees issued in 2009, prohibit import and internal movement of host	Import of palms prohibited (1970). Stringent quarantine regulations are applied. No movement of offshoots
What are the challenges/constrains facing the application of quarantine measures?	Lack of awareness about the importance of Quarantine measures. Lack of commitment to implement Quarantine law	Quarantine applied strictly. RPW was eradicated from the Islands	Preventive control applied in areas where infested palms detected. Very costly	Awareness about the pest is not available	
Are the location of traps and the number of captured RPW known precisely and frequently up- to- date	The location of traps and the number of captured RPW is recorded	GIS used. Trap and Weevil capture data collected.	Traps are checked every week. Data are computerized	Mass trapping is applied and data available	Mass trapping with pheromone traps done in Jordan valley
Are the data used as a tool for decision support regarding the activities?	Data are used as a tool for decision support regarding the activities	Yes.	Yes	Yes. They are used for decision making	Yes
What is the source of offshoots to farmers? Are they controlled by the plant protection services and how? Certified nurseries	Offshoots is available through coordination between farmer and directorate of agriculture Certified nurseries are Tissues culture palms	Accredited nurseries are sources of plants. Certified nurseries available.	There are regular nurseries and tissue culture nurseries	There are no certified nurseries in the country. Source of offshoots are other farmers	
What are the constrains facing the early detection?	Lack of special device to detect the RPW infection in the early stages	All infested palms were eradicated.	Difficulty of early detection	No technology and awareness, poor agronomic	

Table 2. Cont...

Key Components	Saudi Arabia (Country report FAO)	Canary Islands (government source)	Morocco (Country report FAO)	Oman, 2015 (Country report)	Israel
What are the challenges/ constrains facing the management practices?	Non-application of the unified mechanism. Difficult of geography. Human and financial. No biological control	Project successfully completed.	High level and continuous team mobilization; High costs for control	Geographical distribution of palms. Labor cost. Absence of biocontrol	High cost of pheromone trapping. Not sustainable in large areas
What is the role of the Government in supporting the farmers in management of RPW?	Doing all the prevention and control operations	Full support of the government. Passed legislation at the island level	Government through ONSSA is doing control operations & giving materials	Government supports 100% in management of RPW.	Plant protection & Inspection services, Ministry of Agriculture
what is the role of the extension services in the country	Yes, to some extent		Extension agents were trained by FAO and ONSSA		
Have participatory approach and methods been used to implicate the farmers?	Yes	Participatory approach followed	Training and awareness raising workshops with all stakeholders/farmers even in areas that are not infested		
Are incentive and dissuasive (including fines) been used to improve the farmers cooperation	There are no incentive and dissuasive.	No	Control is mandatory. Garden owners comply		
List any other major challenges or constrains that make the RPW management difficult or un successful?	Lack of adequate financial and human resources. Lack of awareness among some farmers and officials. Lack of training	The project was completed and the area was declared RPW free in May 2016.	Intensive surveillance and control is challenging physically for workers and financially costly		

Table 3. Benchmarks for adoption by the Kingdom of Saudi Arabia

S. No	Bench Mark	Country setting the Bench Mark	Challenge for KSA
1.	Prohibition of off shoots with more than 5 cm diameter	Canary Islands	Moving away from 6 cm diameter to 5cm offshoots Strictly enforcing two treatments a year
2.	Preventive control applied quickly where RPW appeared on priority	Morocco	KSA should take up
3.	Government support in amending the law and promulgating regulations	Canary Islands 100 per cent Oman 100 per cent	KSA must amend the legislation
4.	Two preventive treatments a year	Canary Island	Should be enforced
5.	Early Detection using acoustics and dogs	Others	Should be considered
6.	Prophylactic treatments	Others (very imp)	Should be enforced
7.	Accredited nurseries are sources of plants. Certified nurseries available	Canary Islands	KSA must initiate certification of nurseries for accreditation
8.	Tissue culture nurseries to be allowed	Oman	Tissue culture nurseries to be allowed
9.	Training of Extension agents, Farmers and other stakeholders	Canary Islands	KSA to take up
10.	Successful Eradication of RPW with strict enforcement and excellent coordination among the stakeholders	Canary Islands	KSA to build coordination and efforts for enforcement of rules and protocols

As a member of the cluster in the given period of time, the timeline for developing the date palm quarantine system has been put on track during this mission with the following activities scheduled:

- The standalone internal quarantine regulation for the red palm weevil and the strategy to work out pest risk analysis (PRA) for regulated non quarantine pests (RNQP) worked out in accordance with ISPM 21 and ISPM 16, the IPPC standards respectively. As a pre requisite the existing GCC plant quarantine law has been studied thoroughly along with the decree that banned the import of all kinds of palms in to the kingdom. The status of presence of red palm weevil has to be viewed comprehensively as we gear up to consider the weevil as the RNQP and the PRA to that extent in order to exercise the sovereign rights of the kingdom to continue regulation of palm imports.
- Also the strategy to work out for the establishment of strong phytosanitary system which includes developing protocols for removal, shredding and disposal of infested palms along with other farm level phytosanitary measures, has been put in place.
  -A significant and crucial quarantine measure viz., developing appropriate regulatory and incentive measures for production, distribution and use of healthy date palm offshoots (planting material) has been developed and included in the set of recommendations for the Kingdom.
- Once the mechanism of suggested protocols are scrutinized for harmony with other components of integrated strategy including the protocols for the production of tissue culture planting material are ready, demonstration farms that produce certified palm seedlings could be developed in association with the MEWA officials and the other ministries. A pilot programme for the control of red palm weevil in the designated area would eventually find momentum for implementation.

The Way Forward

The current extent of the RPW impact on palm trees is a consequence of the inadvertent movement of cryptically infested plants across different regions and countries. Therefore, the effective control of its ongoing expansion is dependent on a legal framework that effectively regulates the imports of palm trees out of the affected regions. In Europe, where RPW has been responsible for massive mortality of CIDP, any palm used in a new plantation, landscape project or garden should have a valid EU Plant Passport. The movement and trade of palm trees in Europe is conditioned by the Commission Decision 2007/365/EC on emergency measures against the introduction and spread of RPW within the European Union (OJEU, 2007). This decision was modified for the last time in 2010 (OJEU, 2010) and was meanwhile incorporated into national, regional and local laws. It defines quarantine procedures by establishing demarcated infested areas and regulating import requirements and conditions for movement of palms arriving in the EU. As another example, the GCC quarantine law banned the import of palms from any region.

We have examples of successful policy implementation in Canary Islands which had been declared weevil free last in May 2016 after concerted efforts to eliminate the pest. In Mauritania, the government has acted promptly to contain an infestation in an oasis by working closely with farmers. Similarly, the benchmarks established in countries like Saudi Arabia, Morocco, Oman and Israel, should be used as guiding principles to develop a viable policy for adoption in the NENA region.

A new action plan from FAO of the UN

A new action plan that is basically an integrated approach with a variety of components to stop the spread of the red palm weevil has been endorsed at a high-level meeting at the United Nations Food and Agriculture Organization (FAO) in Rome in 2017.

Agriculture ministers and other government representatives agreed on this new strategy to fight the pest. It includes national interventions such as improved pest monitoring and greater involvement of farmers, as well as international efforts such as a proposed ban on the import of palms larger than 6 cm wide from infested countries. The endorsement came after scientists, pest control experts, farmer representatives and others took part in the Scientific Consultation and High-Level Meeting on Red Palm Weevil, hosted by FAO with the International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM), to share the latest research and agree the best way forward.

IPPC standards for protecting the palms

Employing IPPC standards is today’s mantra to deal with the invasive insect pest RPW causing global concern, more so in the NENA region, looking at its invasive spread in the North African and other Mediterranean regions. Looking at the successful policy implementation modules in the EU, such as Canary Islands using the IPPC standards, it is possible eventually to control and eradicate the pest in combination with other IMP strategies (Brunel, 2017).

IPPC has been functioning with its key role as watchdog on the movement of invasive insects and pathogens. The convention is now the global instrument for the harmonization of phytosanitary measures and it is now recognized as the only standard setting organization for plant health recognized by WTO-SPS. Developing International Standards for phytosanitary measures (ISPMs), sharing information with all stakeholders and implementing the convention in letter and spirit and developing phytosanitary capacities of the countries are the key elements for any successful pest suppression programme. As on March 2017, there are 37 standards, 12 diagnostic protocols and 21 phytosanitary treatments, all of them are now available at the click of a button on www.ippc.int.

IPPC implemented national and global projects including legislation and policy advice in Azerbaizan, Botswana, Georgia, Moldova, Namibia, Palestine and South Sudan. Implementing the convention and developing phytosanitary capacities for NENA countries is very crucial, without which it is difficult to manage the RPW menace, leave alone the eradication of the weevil (Figure 2)

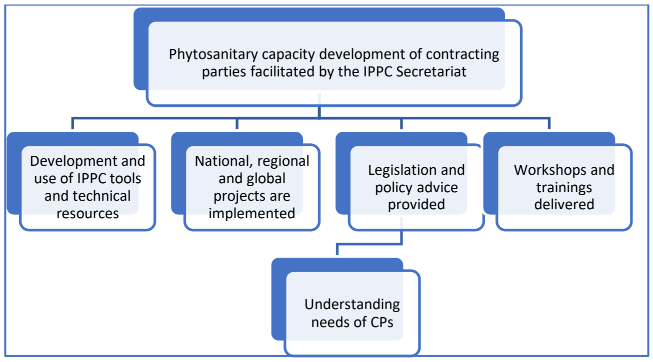

Figure 2. Organogram of objective, activities and expected outcome.

الملخص

[illegible] 2019. [illegible] *Rhynchophorus ferrugineus*؟. [illegible] 37(2): 89-100.

[illegible] 2008 [illegible] 2016 [illegible] 2018 [illegible] IPPC [illegible] 36 [illegible]

[illegible]: *Rhynchophorus ferrugineus* [illegible]

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Billaea rhynchophorae, a palm weevil parasitoid with global potential

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Abstract

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The American palm weevil, *Rhynchophorus palmarum,* is the main primary pest of palms in tropical America and the principal vector of the red ring disease, the major phytosanitary problem of coconut and oil palm in South America. The current management of the problem is based on the capture of adult weevils with aggregation pheromone and the elimination of diseased palms, a system difficult to implement for smallholder producers. Biocontrol agents of the weevil, the tachinid parasitoids *Billaea* spp., are known with limited distribution in Bahía State of Brazil. Their introduction and release in affected areas could greatly improve the natural control of the weevils. Furthermore, these parasitoids are known to attack palm-boring weevils in five different genera and could be a new control option for the red palm weevil, *Rhynchophorus ferrugineus*, the worst pest of palms worldwide. The collection, rearing and study of these parasitoids for introduction in new areas are the aim of this study. A detailed analysis of the necessary steps to comply with regulatory aspects and a research programme to ensure biosafety is described.

Keywords: Palm weevils, *Rhynchophorus palmarum, R. ferrugineus,* tachinid parasitoids, *Billaea rhynchophorae,* host range, risk analysis.

Introduction

Three palm species dominate commercial palm production in South America: African oil palm (*Elaeis guineensis* Jacq.), coconut (*Cocos nucifera* L.) and peach palm (*Bactris gasipaes* Kunth) for production of palm hearts and fruits. All suffer from attack by the American or black palm weevil (APW), *Rhynchophorus palmarum* (L.) (Coleoptera, Dryophthoridae) and a number of other weevil species with varying degree of damage according to the location (Moura, 2017). The American palm weevil is also the major vector for *Bursaphelenchus cocophilus* (Nematoda: Aphelenchidae), which causes the red ring disease (RRD) of coconut and oil palm (Chinchilla, 1991). The APW/RRD complex is particularly serious at the southern Pacific coast of Colombia, where it causes recurrent pandemics that periodically destroy entire coconut plantations along the rivers flowing into Tumaco Bay (Löhr, 2013)

Due to their development within the stem of palms, palm weevil larvae and pupae are largely protected against the attack of natural enemies. At the international level, very little is known about natural enemies of stem-boring palm pests that exert an appreciable degree of natural control. (Murphy and Briscoe, 1999) and more recently, Ortega *et al.* (2017) reviewed the biological control options of the red palm weevil (RPW) and listed several control agents, especially fungi and entomopathogenic nematodes. However, these alternatives present problems in their use, such as the availability of formulated products for farmers and the difficulty of application in adult palms. A biocontrol option that has been overlooked but seems to be the most promising of all natural enemies of palm weevils known so far are parasitoid flies of larvae and pupae (Löhr, 2013): *Billaea menezesi* (Townsend) (Diptera: Tachinidae) was identified more than 25 years ago in oil palm in southern Bahia/Brazil, where parasitism rates up to 72% have been reported (Moura *et al.,* 1993). More recently, *Billaea rhynchophorae* (Blanchard, 1937) was registered as palm weevil parasitoid in the same area on oil palm and a native palm species, *Attalea funifera* Martius (Arecaceae) (Moura *et al.,* 2006).

A new threat to the palm industries in South America is the arrival of the red palm weevil (RPW), *Rhynchophorus ferrugineus* Olivier (Coleoptera: Dryophthoridae) via the importation of infested date palms to the Dutch Antilles in 2008 (Kairo, 2010). The red palm weevil has a long history of invasions, first to the Middle East resulting in huge losses (El Sabea *et al.,* 2009), then the Mediterranean (Barranco *et al.*, 1995), China (Ju and Ajlan, 2011), Japan (Aman, 2001), and Malaysia (Azmi *et al.*, 2013) and hence has to be taken seriously. Even though the problem at present seems to be limited to the Dutch Antilles, their proximity to the South American continent could facilitate its spread. Hoddle *et al.* (2015) demonstrated in flight mill studies that RPW has the capacity to fly up to 50 km in a day, double the distance of Aruba to the continent.

Here we analyse the current situation and present an action plan for the control of the American palm weevil and to prevent an invasion by the red palm weevil. We also analyse the possibilities for the use of the parasitoids in non-tropical areas affected by palm weevils and propose ways for their integration in IPM programs.

Identification of Local Mortality Factors in Colombia

Before embarking on an introduction biocontrol project, the local natural enemies of the target species should be known. Studies conducted in Colombia identified a larval predator, *Hololepta* sp. (Coleoptera: Histeridae), very common at the Pacific Coast and the Eastern Plains. However, due to its small size (3 mm) its value as palm weevil predator is

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doubtful and it is probably more interested in the thousands of sarcophagid fly larvae that are invariably found in decomposing palm stems. Another histerid predator, *Oxysternus maximus* L. was first reported by Fanny Alvañil at Cumaral/Meta in Colombia (Posada *et al.,* 1990). Large numbers of this species were collected in an abandoned, bud rot diseased oil palm plantation at Acacías/Meta (Löhr, unpublished). Attempts to multiply the species were given up when the females produced only one egg per week (G. León, personal communication). This species was later also found in very low numbers at the Pacific coast (G. León, personal communication). Several entomopathogenic fungi have also been identified, mostly *Beauveria bassiana* Vuillemin and *Metarhizium anisopliae* (Metschnikoff) Sorokin (Aldana *et al.,* 2010, 2011).

Fly puparia have been recorded with cocoons of *R. palmarum* in Colombia on two occasions: the palm weevil management handbook of the National Center of Palm Research mentions four fly puparia found in Tumaco in oil palm (Aldana *et al.,* 2011). A single fly emerged and escaped before being identified (R. Aldana, personal communication). And in a sample of 713 large larvae and cocoons, Ramirez (1998) found a single fly puparium that could not be identified either. In later surveys in Guapi, Timbiquí, Tumaco Bay and in the Eastern Plains, with over 370 larvae and pupae examined, the existence of parasitoids could not be confirmed (B. Löhr, unpublished).

An Untested yet Promising Option: the Moura Flies of Brazil

Alternative biocontrol agents that have not received due attention in the reviews of biocontrol agents (Murphy and Briscoe, 1999; Ortega *et al.,* 2017), are the tachinid parasitoids of APW larvae and pupae, *Billaea menezesi* (Townsend) and *Billaea rhynchophorae* (Blanchard) (Diptera: Tachinidae). The former species was identified first more than 25 years ago in the south of Bahia/Brazil, where parasitism rates of up to 72% were reported (Moura *et al.,* 1993). In a later study, an average 50% of large larvae and/or pupae were found parasitized in oil palm and *Attalea funifera* (Mart.), a native palm species of Brazil (Moura *et al.,* 2006). However, in spite of these high parasitism rates, detailed studies on the biology or ecology of these species have never been conducted, nor have introductions to new geographical areas been attempted as was recommended in Moura´s first publication: "The area of distribution of the fly in South America and also in Africa and Ásia could be augmented for the control of related species" (Moura *et al.,* 1993).

There is a taxonomic confusion regarding this fly since in the first publication, Moura *et al.* (1993) referred to *Paratheresia* (now *Billaea*) *menezesi* and in the second to *Billaea rhynchophorae* (Moura *et al.,* 2006). According to Silvio Nihei (personal communication), tachinid taxonomist of the University of São Paulo, the two species names are valid; so there are possibly two species of palm weevil parasitoids in Brazil.

Considering as a starting point the climatic conditions where the species were found in Brazil, areas with similar climatic conditions in the Americas were mapped out using Homologue™ (Jones *et al.,* 2005).

The results indicated that the parasitoids could be established in the most important coconut and oil palm areas in Colombia and other Latin American countries (Figure 1).

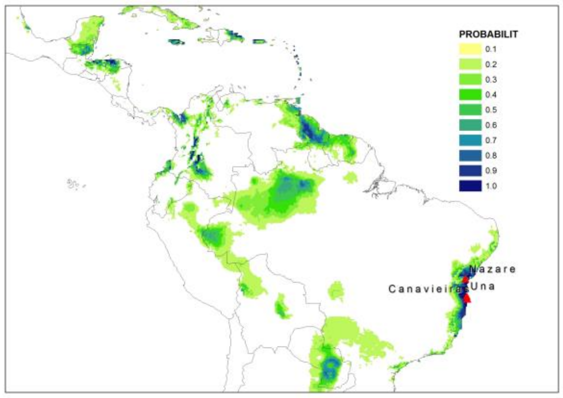


Figure 1. Climate matching chart between area of endemism and possible introduction of *Billaea rhynchophorae* in the Americas. Red triangles mark the locations where the flies have been collected. Map elaborated using Homologue™ (Jones *et al.,* 2005).

Regulatory Aspects

Any work in Brazil that involves the collection of specimens by foreign entities can only be done in cooperation with a Brazilian research institution and requires special permits. Furthermore, collection, rearing, research as well as export and import of biological material is subject to the regulations of Brazilian Institute of Environment and Renewable Natural Resources (IBAMA). The Brazilian Government, through IBAMA, provides the SisCites system for requesting, evaluating and issuing licenses for collection, research and eventual export of specimens of Brazilian wildlife. The legally established period for processing licences is 60 days and the validity of licenses is 180 days.

The importation or exportation of fauna is based on the following IBAMA standards: 1) Ibama Ordinance No. 93/1998, that regulates the import and export of live specimens, products and by-products of Brazilian and exotic wildlife; 2) Normative Instruction Ibama No. 140/2006, that establishes the Ibama application and licensing service for the import, export and re-export of specimens, products and by-products of Brazilian wild fauna and flora; and 3) Decree No. 3607 of September 21, 2000, that provides for the implementation of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and other measures.

Biology and Ecology of Tachinidae

The Tachinidae family is one of the largest dipteran families, with more than 8200 described species (Cantrell and Crosskey, 1989), all parasitoids of other arthropods. Tachinids are very common flies and the great majority are parasitoids of lepidopteran larvae (Stireman *et al.,* 2006; Vincent, 1985). The family is subdivided into four (Wood, 1987) or five (Crosskey, 1976) subfamilies according to their biology and morphology. The genus *Billaea* belongs to the Dexiini subfamily which is distinguished by generally large specimens and by incubating its eggs in the oviduct. Females deposit live larvae or eggs that emerge immediately after oviposition (Clausen, 1940).

The fertility of females is generally high and, depending on the species, they produce between 500 and 3000 eggs (O'Hara, 1985). Most species in the subfamily attack plant-boring coleoptera hidden inside the plant tissue (Nihei and Pavarini, 2011). Therefore, females do not have direct contact with their host, but deposit their larvae or eggs onto the frass produced by the larvae of the borers or into the openings of the larval galleries (Arnaud, 1978; Campadelli and Gardenghi, 1991). The emerging planidia have to look actively for their host, following the feeding tunnel in the plant material (Rodriguez del Bosque and Smith, 1996; Suazo *et al.,* 2006). Although there is no detailed information on *B. rhynchophorae* and *B. menezesi*, it is expected that they belong to this type of parasitoid.

Despite the first detection of the parasitoid flies more than 25 years ago, to date there is no detailed information on their biology. Fly puparia have mostly been found in pupal cocoons during the elimination of red ring diseased oil palms. This may just be a sampling bias but it could also hint to an endocrinological relationship between parasitoid and host as has been observed in other cases in Tachinidae (Baronio and Sehnal, 1980; Mellini, 1986).

The age of the host larvae is an important factor for the success of the parasitism of Tachinidae (Mellini, 1986, Terkanian, 1993) as well as the number of larvae that attack the host at different ages: an excess of parasitoid larvae results in mortality of part of them or death of the host (Bobadilla, 1992). The viviparous nature of the Moura flies allows for forced inoculation of potential hosts (Figure 2, and Figure 3) or weevil larvae of different ages/weights with different numbers of parasitoid planidia to determine the ideal combination (Gross, 1988; Gross *et al.,* 1985).

Host/Parasitoid Interaction in Different Palm Species

The host searching behaviour of tachinid flies is largely unknown. Circumstantial evidence indicates that the percentage parasitism by *Billaea* spp. varies between different palm species with higher rates in oil palm than in coconut or *Attalea funifera* (J.I. Moura, personal communication).

This may be due to variations in the behaviour of the weevil larvae in different palm species, or to differences in the preference of the flies for kairomones emitted by different palm species. Several studies have shown that tachinid species are able to distinguish between kairomones from different plants (Montieth, 1955, 1963; Roland *et al.,* 1989; Roth *et al.,* 1982) as well as host secretions or frass produced by borers (Clement *et al.,* 1986; Suazo *et al.,* 2006). However, recent data show that a congeneric species, *Billaea claripalpis* Wulp, indiscriminately parasitizes *Diatraea saccharalis* F. (Lepidoptera: Crambidae) (a suitable host) and *R. palmarum* (an unsuitable host) larvae in sugarcane when both are offered simultaneously (J. Gaviria, in preparation).

Figure 2. *Billaea claripalpis* ovary with emerging planidia and brush for transfer of planidia onto a host for host suitability testing

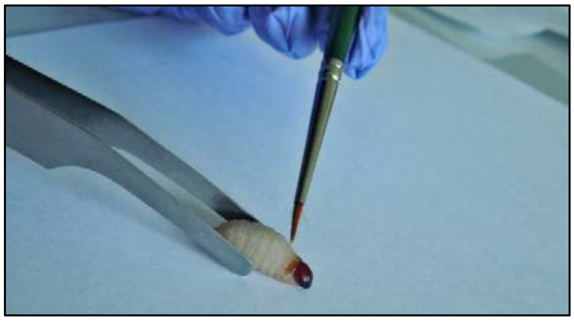


Figure 3. Transfer of *Billaea claripalpis* planidia to *Rhynchophorus palmarum* larva for host suitability testing.

Host Range of *Billaea* spp.

Host range studies are central to the risk assessment for a parasitoid considered for introduction elsewhere. This is particularly true for Tachinidae species whose host range in general is considerably wider than in other parasitoid families (Eggleton and Belshaw, 1993). Therefore, the first consideration in the case of *Billaea* is of taxonomic nature: *Billaea* belongs to the Theresiini tribe of the subfamily Dexiinae that has specialized on coleopterous borer larvae, mainly of the Dryophthoridae family (Nihei and Pavarini, 2011). According to these authors, the only exception is *B. claripalpis*, widely used in Colombia for biological control of the sugarcane borer, *D. saccharalis* (Vargas, 2015).

The vivipary of the Moura fly facilitates the host range studies by allowing the manual infestation of different potential host species or weevil larvae. The host testing procedure generally starts with species that are taxonomically and ecologically close to the target species (other palm weevils), casting the net wider with every step (lepidopterous palm borers) then lepidopterous palm foliage feeders until the researcher and the authorities are satisfied. Circumstantial evidence indicates that *B. rhynchophorae* can attack several other weevil palm pests such as *Dynamis borassi* F., *Rhinostomus barbirostris* F., *Homalinotus coriaceus* Gyllenhal and *Amerhinus ynca* Sahlberg (Moura *et al.,* 2002), all of which will be investigated for host suitability.

The next species to be tested is *Eupalamides daedalus* (F.), (Lepidoptera: Castniidae), an occasionally serious palm-boring lepidopterous species occurring in Pará and Amazonas States of Brazil (Moura, 2017) and a congeneric species (*Eupalamides guyanensis* Houlbert) is know from the Eastern Plains of Colombia (Aldana *et al.,* 2010). In both cases, efficient natural enemies are not known and an effect of *Billaea* spp. On this pest might be considered a welcome addition to their list of mortality factors.

Any parasitism outside the group of palm-boring insect species is not acceptable. Considering the known preference of Tachinidae for lepidopterous larvae (Vincent, 1985), a number of lepidopterous foliage-feeding species of palm pests will be studied as alternative hosts: *Brassolis sophorae* L., a gregarious and *Opsiphanes invirae* Hübner, a solitary species (both Lepidoptera: Nymphalidae), and *Synale hylaspes* Stoll (Lepidopter: Hesperidae). The host testing procedure is outlined in Figure 4.

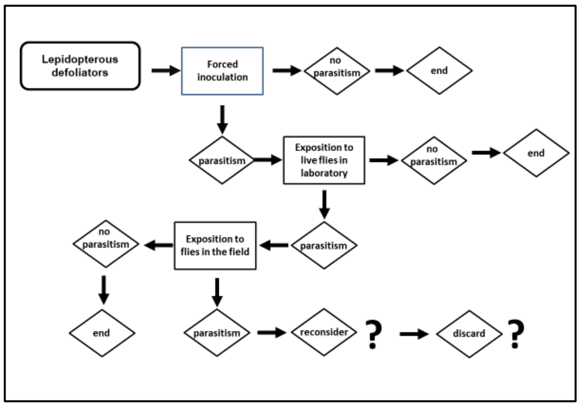


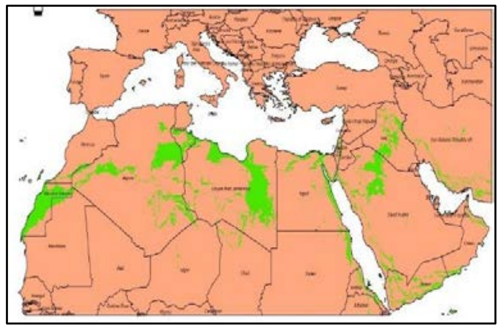
Figure 4. Schematic process of host suitability testing for possible alternative host species of the palm weevil parasitoid *Billaea rhynchophorae* (Diptera: Tachinidae).

Mass Rearing of *Billaea* spp.

In vitro production of biologically and behaviourally normal Tachinidae in complete absence of the host and in artificial diet free of any component coming from hosts has been developed for four species (Dindo and Grenier, 2014) and there is a considerable volume of publications dealing with the different aspects of this process (Dindo *et al.,* 2007, 2006; Bratti and Nettles, 1992; Mellini and Campadelli, 1996). The success of in vitro rearing depends on the biology of the parasitoid and the endocrinological relationship between host and parasitoid, host-dependant parasitoids generally being more difficult to rear on artificial medium (Dindo, 1998; Thompson, 1999). Both are unknown at present, making a prediction for the outcome of these efforts difficult. Nevertheless, a mass rearing system would be very useful in case of an invasion of the red palm weevil in South America. Mass rearing could also facilitate the use of the Moura flies in areas where climatic conditions do not allow permanent establishment, but would allow the use of the flies during favourable periods of the year like the Mediterranean (Figure 5) and the Middle East regions (Figure 6).

Risk Analysis

The risk analysis will be based on four components: taxonomy, host range tests, adult fly behaviour and fly ecology. The taxonomic position of the genus *Billaea* in the tribe Dexiini, a grouping of flies with exclusively viviparous or ovoviviparous reproduction and coleopterous hosts is a strong indication of specialization. This is reinforced by the existing host records for the genus *Billaea*: almost all known hosts are larvae of coleopterous borers of woody plants, the only exception is *Billaea claripalpis* Wulp, a parasitoid of *D. saccharalis* in sugarcane (Nihei and Pavarini, 2011). The taxonomic information alone is already an indication of high specialization of the Moura flies and consequently a low risk associated with an introduction. Further information will be obtained from the studies of host range, fly biology, and fly behaviour. The analysis of the combined results of these studies will allow a sound judgement of the risk associated with an introduction of the flies into areas where they do not exist at present.



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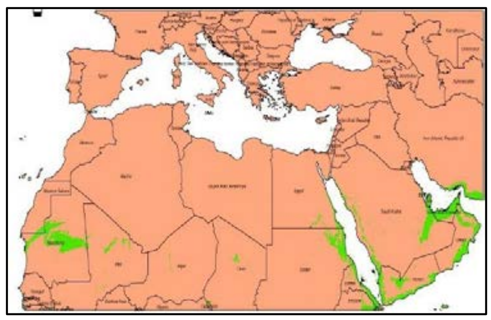

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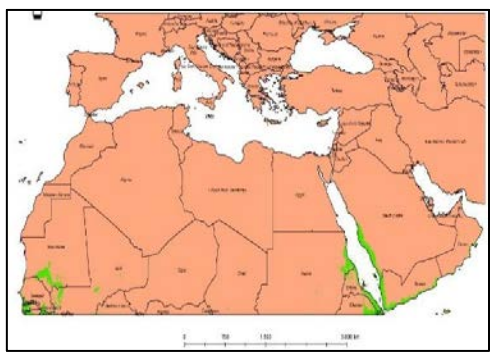

December

Figure 5. Areas (in green) and periods where Brazilian palm weevil parasitoids (*Billaea* spp.) could be released in the Mediterranean. (Temperature range 17-32°C, maps developed by Angela Castaño).

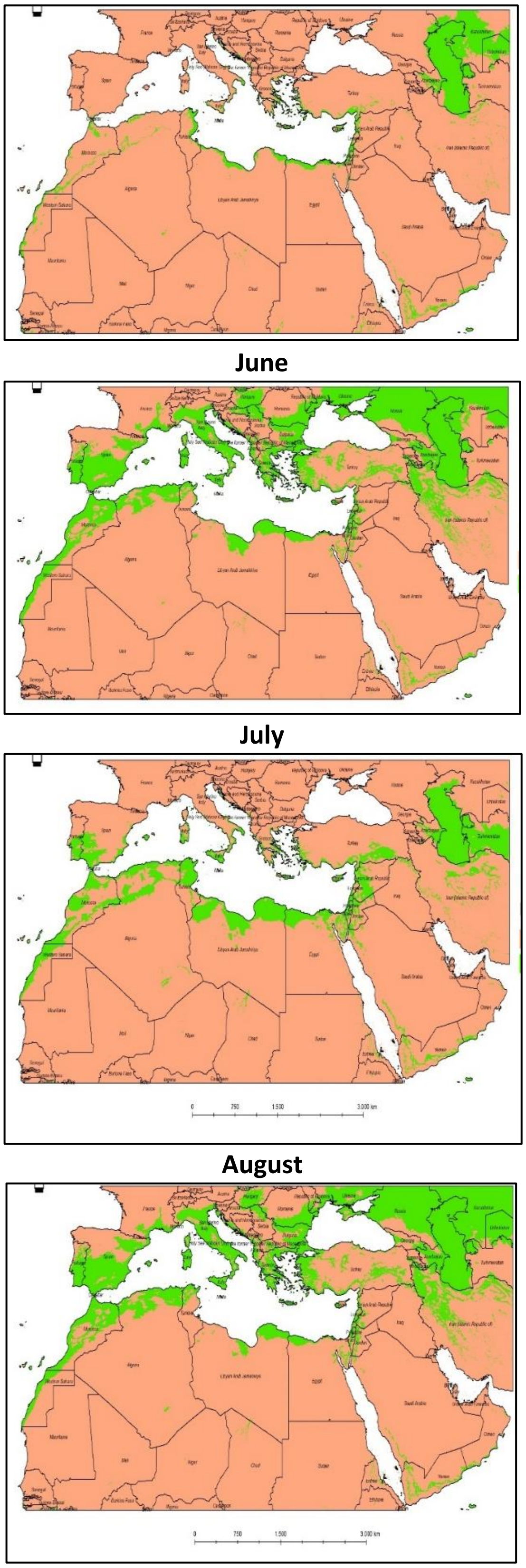

Figure 6. Areas (in green) and periods where Brazilian palm weevil parasitoids (*Billaea* spp.) could be released in the North Africa, Red Sea, Arabian Peninsula and Persian Gulf. (Temperature range 17-32°C, maps developed by Angela Castaño).

Quarantine and Export Permit for *Billaea* spp.

Risk analysis and quarantine processing are the two principal requisites before a parasitoid can be considered for importation. The Brazilian Corporation of Agricultural Research operates quarantine facilities and has qualified staff for quarantine processing of insects at their research station in Jaguariuna/São Paulo. All flies considered for export will have to pass one generation at this station and undergo the necessary screening to ensure no unwanted organisms (hyperparasitoids, diseases and particularly problems of possible transovarial transmission such as microsporidia) accompany the parasitoids. Export permits will be processed by EMBRAPA IP Department.

The Moura Flies and *R. ferrugineus*

In view of the recent introduction of RPW to the Dutch Antilles and other imminent pest invasions, EMBRAPA organized a symposium on invasive species in Boa Vista/Roraima in May 2015. One of the results of this symposium was the development of a cooperative research programme between EMBRAPA and Corpoica (now AGROSAVIA) to get prepared for an eventual invasion by the red palm weevil by researching possible control methods beforehand. Therefore, the general objective of our initiative is to increase the natural control of APW in areas outside the natural distribution of tachinid weevil parasitoids and to develop control options that can be used in case of an accidental introduction of RPW to the South American continent.

Due to the biological similarity between the black and red palm weevil, it is expected that *Billaea* spp. will work as a biological control agent against this new pest in the Caribbean islands and thus could be used in an eradication attempt on the islands to avoid an invasion of the South American continent with unpredictable consequences. In addition, the species might be a welcome addition to the control options in other areas affected by *R. ferrugineus*.

To generate maps of areas and seasons suitable for liberations of *B. rhynchophorae*, we used 17°C as lower and 32°C as upper limit and crossed these with data of the minimum and maximum temperature in multi-year monthly averages published by Fick and Hijmans (2017). The maps were created using R software, through the functions included in the packages Raster and Tiff, generating an output file for each month. Subsequently, the files generated were loaded into ArcGIS® and ArcMap™ software and cut to fit the coordinates of the study area. According to this analysis, conditions in the Mediterranean should allow seasonal releases from July to October (Figure 5) and in the Red Sea and Persian Gulf and Arabian Peninsula from October to December (Figure 6). Parasitoid releases should be an ideal complement to trapping as they are effective against the larval population, and the host searching abilities of the flies should ensure parasitation of larvae that might be undetectable by any means available at present.

Conclusions

Even with the limited knowledge available, the potential of the Brazilian tachinid parasitoids for palm weevil control in areas beyond its natural range of occurrence is obvious. Research on the biology, chemical ecology and host range should demonstrate their potential for introduction biocontrol in other areas of the humid tropics and the possibility of use in controlled release operations in areas where the climatic conditions do not allow permanent establishment.

Acknowledgements

We are indebted to José Inacio Moura for his advice during the development of the research project and all the circumstantial evidence about parasitoid ecology. Rafael Reyes was instrumental in overcoming the legions of bureaucratic obstacles during project development. Jackeline Gaviria and Freddy Suarez conducted most of the weevil parasitation experiments with *Billaea claripalpis*, the sugarcane moth parasitoid, our model parasitoid, and Angela Castaño produced the maps of areas suitable for seasonal releases of the parasitoids in the Mediterranean and Near East/North Africa region. All are gratefully acknowledged.

الملخص

لور، برنارد، أدولفو إيبونغ ريس لوبي وخوان باولو مولينا. 2019. *Billaea rhynchophorae* متطفل على سوسة النخيل بإمكانات عالية. مجلة وقاية النبات العربية، 37(2): 101-108.

تعدّ سوسة النخيل الأمريكية *Rhynchophorus palmarum* آفة رئيسة لأشجار النخيل والناقل الرئيسي للديدان الخيطية المسببة لمرض الحلقة الحمراء في المناطق المدارية من أمريكا، كما أنّ هذا المرض يلحق الضرر الأكبر في مايخصّ الصحة النباتية لأشجار جوز الهند ونخيل الزيت في أمريكا الجنوبية. وتعتمد إدارة المرض حالياً على المصائد الفرمونية للسوسة باستخدام الفيرومونات التجميعية وإزالة النخلات المصابة، وهذا نظام يصعب تطبيقه من قبل المزارعين ذوي الحيازات الصغيرة. ومن بين عوامل المكافحة الحيوية للسوسة، يعرف ذباب التاكينيد .*Billaea* spp كمتطفل ذي انتشار محدود في ولاية باهيا البرازيلية؛ وإنّ عملية إدخاله وإطلاقه في المناطق التي تتضرر يمكن أن يعود بالنفع الكبير في مايخصّ المكافحة الطبيعية لحشرات السوس، فضلاً عن ذلك تتعرف هذه المتطفلات وتتقدم على مهاجمة خمسة أجناس مختلفة من ثاقبات النخيل، ويمكن أن تكون خياراً جيداً لمكافحة سوسة النخيل الحمراء *Rhynchophorus ferrugineus* والتي تعدّ أسوأ آفة لأشجار النخيل في العالم. يتضمن أهداف هذا البحث على: جمع، وتربية، ودراسة هذه المتطفلات لإدخالها إلى مناطق جديدة. وسيتم عرض تحليل مفصل للخطوات الضرورية للمواءمة مع الجوانب التشريعية، وبرنامج وضمان الأمان الحيوي.

كلمات مفتاحية: سوس النخيل، *Rhynchophorus palmarum*، *R. ferrugineus*، طفيليات ذباب التاكينيد، *Billaea rhynchophorae*، المدى العوائلي، تحليل المخاطر.

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The world situation and the main lessons of 30 years of fight against the red palm weevil

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Abstract

Ferry, M. 2019. The world situation and the main lessons of 30 years of fight against the red palm weevil. Arab Journal of Plant Protection, 37(2): 109-118.

For the last 30 years, imports and movements inside the countries of infested palms have led to the introduction and the spread of the RPW in all the countries of the NENA region (expected Algeria and Sudan) and in all the countries of the Northern Mediterranean coast. Most of these imports and movements have been officially authorized. In the Mediterranean region, hundreds of thousands of ornamental palms were imported from Egypt between 2000 and 2007. In all the infested countries the programmes to control this pest failed and the present situation is presently very serious with important socio-economic impacts in date producing countries and major landscape damages in places where palms were planted for ornamental purpose. To propose valid and sustainable solutions to control this dreadful pest, it is essential to draw lessons from this widespread failure and from the few cases where the control of this pest was successful. These main lessons are: imports and movement of palms must be forbidden when the shoots measure more than few cm diameter; containment strategy fails if it is not associated with efficient programmes implemented to obtain rapid RPW decline; eradication conceived as a long term objective represents a strategic mistake; with the existing tools, eradication is possible; the paradigm that pest eradication means automatically infested palms eradication is wrong; the main problem is not technical but socio-economic and organizational; socio-economic studies must be urgently realized and participatory approach methods must be implemented to involve the palms owners and their organizations at a large scale in the RPW rapid decline and eradication programmes.

Keywords: *Rhynchophorus ferrugineus, Phoenix dactylifera, Phoenix canariensis,* ornamental palms market, eradication, rapid decline, containment, NENA region, Mediterranean region, socio-economy, phytosanitary regulation, sanitation, management, participatory approach, IPM, GIS.

Introduction

The origin of the world RPW spread (Fig. 1) is anthropogenic, not accidental and, in general, not due to illegal introduction of palms. RPW was introduced from infested country to other countries with infested imported palms.

The importation of palms responds to two different demands: the demand for selected seedlings for coconut or dates production; the demand for ornamental palms that has increased a lot over the last 20 years because palms have become worldwide fashionable landscape trees.

In the infested countries, RPW spreading is also mainly due to movement of infested palms. Indeed, its dispersal behavior is aggregative (Faleiro *et al.,* 2002; Massoud *et al.,* 2012). It is very sensitive to the dryness of the air (Aldryhim and Khalil, 2003; Monzer and Hesham, 2009), a factor that limits to very short distances its own capacity of displacement in the dry regions.

Furthermore, the flying behavior of the RPW corresponds to movements that are not straight, except for short distances; it is used to do laps (Personal observations). Therefore, the results obtained with flight mills (Hoddle *et al.,* 2015) must be taken with precaution before extrapolating them to field conditions. Consequently also, expressions like "RPW has spread", "it has expanded", etc should be replaced by RPW has been spread, expanded, dispersed, etc. For the same reasons, calculating the RPW displacement per year based on the distance between countries or oasis where the RPW is successively detected, does not have much sense.

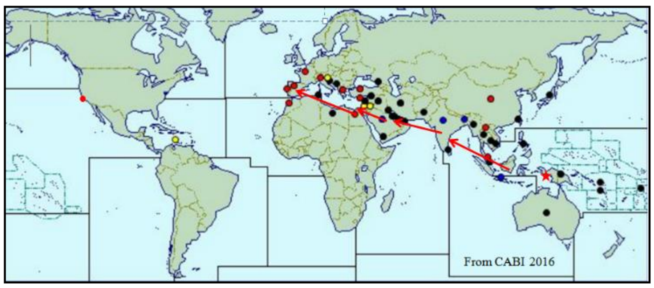

Figure 1. A map showing the world spread of the red palm weevil, due to infested palms exchanges.

The zone of origin of the RPW is South-East Asia. It has been reported in India around 1900 where it has become mainly a coconut pest. Nearly a century later, it was introduced in various places of Eastern region of the Arabian Peninsula and is now present in all the countries of this region, where it has become the main pest of the date palm. It was introduced in 1992 in Egypt, and in 1999 was discovered in Israel and Jordan. It was also introduced in a small area in Spain in 1992. From this last location, contrary to what is sometimes written, it did not spread, naturally or through infested palms exchanges, to the rest of Spain. The explosion of the RPW in Spain as well as in the other Mediterranean countries is linked to an intense trade of

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palms imported from Egypt and from ornamental palms of the nurseries that were infested through these imported palms. In less than 10 years, all the Mediterranean countries, except Algeria, were infested.

RPW is a rapid palm killer. When a palm is infested, if nothing is done to sanitize it, it will be killed inevitably (natural recovering are exceptional) and rapidly, regardless of its size.

Consequently, it is the cause of the death of a very large number of date palms in Egypt and in the Middle East with serious economic consequences, although economic studies are nearly totally missing to assess precisely the dimension of the problem.

In the Mediterranean region, except in Egypt, Jordan and Libya where it is affecting date palms (In Israel, it is affecting now *Phoenix canariensis* and date palms), the main consequences of its presence is the hecatomb, in less than 15 years, of probably around one million of *Phoenix canariensis* planted in the cities, a great part of them of large size and exceptional patrimonial value. This species has constituted nearly 100% of the palms that have been killed by the RPW (without considering the smaller palms killed in the nurseries). The specific hecatomb of *Phoenix canariensis* is due to two reasons: (1) this palm specie has been planted abundantly in all the Mediterranean cities during the last two centuries; (2) RPW has high preference for *P. canariensis* as compared to date palm of more than 2-3 meters (rarely attacked), or *Washingtonia robusta* and other different small palm species that are also abundant in the cities.

For more than thirty years, programmes have been implemented to control this pest. For more than 20 years, the strategy and the techniques to eradicate this pest on date palm have been established (Abraham *et al.,* 1998) and confirmed (Faleiro, 2006). On *Phoenix canariensis*, the strategy and techniques to eradicate this pest was established in 2007 and 2008 (Ferry and Gómez, 2007a; Ferry and Gómez, 2008). In the few cases where these strategy and techniques were implemented, they perfectly demonstrated their efficiency to eradicate the RPW.

Taking into consideration the seriousness of the situation, it is urgent to draw lessons, from this long experience to control or to eradicate the RPW, to identify the mistakes that were made and to propose solutions to solve them.

The Situation in the Northern and Eastern Mediterranean Countries

As already indicated, all the countries of the region are heavily infested, with the pest, present in nearly all the places where *Phoenix canariensis* is present. The hecatomb of palms of this species has been very rapid and considerable because of inappropriate regulations and technical measures (Ferry and Gómez 2007b; Ferry and Gómez, 2013), weak or absent management at the national, regional and local levels, and lack of organization to implement collective action plans, conceived to obtain the quick decline of the pest population.

Only in one place, the Canary Islands, where the RPW was infested *Phoenix canariensis* in the cities, the pest was eradicated rapidly (7 years) and therefore, fortunately, never reached the wild *Phoenix canariensis* forests (Fajardo, 2017a).

The failure has been so important in the European countries that in 2017 the European Commission decided not to register the RPW in the quarantine pest list except in United Kingdom, Ireland, Azores (CE, 2017).

The case of Israel is different, but the outcome is now more or less similar. In Israel, where the first RPW outbreaks were perfectly eradicated between 1999 and 2002, a new outbreak on *Phoenix canariensis* in the northernmost city of the country was discovered in 2009. Unfortunately, the management of this new outbreak followed the disastrous pattern similar to the one adopted in Europe. Consequently, RPW has reached the date palms plantations since 2013 (personal observation) and it is now widespread in most of the country.

Present Situation in the Near East and North Africa Region

Quantitative Data on pest status are generally absent. Therefore, the analysis for each country will be essentially qualitative.

Mauritania

Official notification was made in December 2015. The pest was introduced in only one oasis (Tidjikja) with infested offshoots imported in a container from the U.A.E., as a consequence of an unsatisfactory respect of the regulations.

Eradication is under way. No captures were observed in traps and no new infested palms were detected since April 2017 (N. Nasr, personal communication).

This promising result can be attributed to various reasons:

- The FAO North Africa Project from 2012 to 2013 during which technicians for the PPOs of each North Africa countries, including Mauritania, were sensitized on the seriousness of this pest and trained on the different components for RPW control (Ferry 2012a, Ferry 2012b).
- Very quick reaction of the PPO in Mauritania when infested palms were discovered and rapid elaboration and implementation of FAO/Ministry of agriculture urgency project for the eradication of the RPW, with rapid supply of the products and equipments necessary to implement the different components of the eradication strategy.
- Immediate and constant mobilization of the Government at the highest level.
- Strong early involvement of Tidjikja palms owners. This fact to a great extent explains the results obtained.
- Various missions of FAO RPW experts to assess the situation and the activities and to train the staff of the Ministry of Agriculture and the farmers (Faleiro *et al.,* 2017).

Morocco

Official notification was made in December 2008. Possible introduction via RPW adults accidentally transported by vehicles and boats from Spain to Tangier or via small ornamental palms introduced from Spain.

Reinforcement of the legislation that prohibits now totally any importation of palms of more than 6 cm diameter.

Detection of the pest until 2016 only occurred in the city of Tangier, where it has affected only the ornamental *Phoenix canariensis*, especially the tall ones. Important means were immediately devoted to the eradication project. All the activities were under the control of PPOs. Very quick organisation of a training of the national team by an expert from the Phoenix research station was implemented (July 2009), followed by the reinforcement of the training through the North Africa FAO Project for the control of the RPW.

Results in Tangier: RPW has been contained in the city of Tangier. In the infested sector, the number of new yearly infested palms fluctuates now around 50.

New outbreak in Nador was discovered in 2016. Probably because of the natural dispersion of RPW coming from infested palms in the neighbor city of Melilla where the RPW has not been eradicated (in contrast with Ceuta where no new infested palms have been detected for the last 3 years). The number of infested palms detected in 2016 and 2017 was relatively important as they represented 8% of the total number of palms (El Iraqui, personal communication, 2018).

Algeria

Not present. Reinforcement of the regulation (palms imports totally prohibited) and of the control at the borders. Awareness campaigns in the whole country and especially in the oasis are launched.

Tunisia

Official notification was made on December 2011. Introduced from ornamental palms imported illegally from Italy.

First detected infested palms were in Cartage (North of Tunis) on *Phoenix canariensis*. Now RPW is spread in most of the cities of the Great Tunis, but it has been also detected in Bizerte and Hammamet.

All the activities were under the supervision of the Ministry of Agriculture.

The containment in its original sector of infestation failed. As demonstrated by the worldwide experience, when RPW is not sufficiently well controlled in the infested areas to obtain its rapid decline, its containment is doomed to fail. Among other aspects, the actual presence in the infested areas of Tunisia of numerous infested palms that are abandoned or sanitized (or eradicated) too late makes impossible to obtain such decline and, consequently, to avoid the further accidental dispersal of the RPW.

The plan of action proposed by FAO in 2012 (Ferry, 2012c) was implemented in its totality and efficiently by a team of the Ministry of Agriculture exclusively dedicated to this plan during the first semester of 2014: communications, location of all the palms, frequent inspection of the palms for early detection, immediate sanitation of the infested palms or eradication of the infested parts (palm head feeling and eradication), mass trapping, preventive treatments (Head felling and eradication of infested palms constitute a provisional measure to eradicate more rapidly the RPW present in an infested palm. Nevertheless, the remaining trunk, even if it is not anymore a potential host of the RPW, has to be to cut later, because it presents a risk to fall down in the future).

Because RPW decline has not obtained and, especially, because of the presence of infested palms that are not sanitized or eradicated sufficiently rapidly, the risk of an accidental introduction of RPW in the oasis is now very high.

Libya

The RPW was first detected in Tobruk in January 2009, and was detected a bit later in Tripoli. Little information is available regarding this country. It is supposed that the pest was introduced in Tobruk from date palms coming from Egypt, and in Tripoli from ornamental palms coming from Tunisia. From the first infested palms in Tripoli, the pest has spread to the farms around this city.

The implementation of the plan of action to eradicate the RPW proposed by FAO in 2012 could not be initiated. Nevertheless, technicians of the Libyan PPO have at least benefited of the training organized in Tunisia and the study tour organized in Oman in 2012 by FAO.

There is a preoccupation in Tunisia that the possible import of offshoots of one reputed Libyan variety could introduce the pest in the Tunisian oasis that are close to the border.

Egypt

The RPW was detected in Egypt in 1992. It was introduced from offshoots imported from Saudi Arabia or the UAE. It was detected initially in two small places in the Governorates of Sharquiya and Ismailia (Cox, 1993).

Eight years later, more than 200000 infested palms were detected in 13 different governorates (El-Sebay, 2007). Figure 2 (El-Sebay, personal communication, 2007) shows the locations where the RPW was introduced from 1992 to 2000.

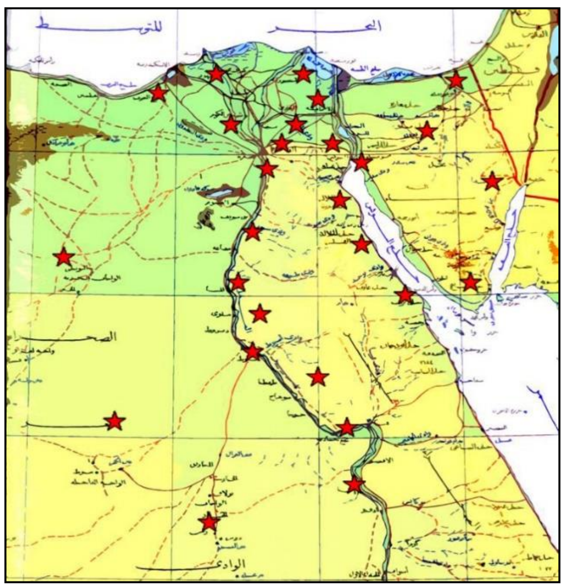

Figure 2. Spread of red palm weevil in 2000 (El-Sebay, 2007).

The quick dispersion of RPW in the whole country was not the result of the natural RPW spread between oasis. It was due to the movements of infested date palms for ornamental use and of infested offshoots from tissue culture palms (2006 personal observation in new planted area in Egypt) as well probably of new offshoots imports.

The RPW control programme is now principally in the hands of the farmers, who, because of insufficient training and lack of extension agents, lack of sufficient knowledge on the pest and on the way to control it. The number of infested farms and infested palms in the farms is increasing. This situation is made worse in places with new plantations as young date palms are much more susceptible to RPW than palms without offshoots or with trunk of more than 2-3 m high (In higher and older palms, tissues of the petioles bases along the trunk are dead or too dry for successful oviposition) (Ferry, 2017).

Sudan

RPW is not present, but there is a high risk of introduction as palms importation is not totally prohibited and establishment of new large date palms plantations is planned.

Jordan

The RPW was detected in Jordan on date palms in 1999 in a plantation located in the Jordan Valley at Shuna, not very far from one of the infested sites discovered in Israel during the same year. The programme to control the RPW was implemented by the Ministry of Agriculture. RPW was successfully contained in the small area where it was initially found and it was considered eradicated or at least very residual in 2005 (Dr. Mona Mashal, personal communication, 2018).

Another outbreak very far from the first one was discovered in 2013 in Azraq. The infested area is much more important. More than 400 date palms were eradicated in 2016.

Palestinian territories

West bank - In this part of the territory, palms are essentially ornamental. RPW from the infested *Phoenix canariensis* present in growing number in Israel, including in Jerusalem, are also infesting the *Phoenix canariensis* of the West Bank.

Jericho - RPW was only captured in traps. As the plantations are still young, risk of infestation is high (Ferry, 2014).

Gaza - RPW discovered for the first time in September 2011 in a nursery of the central zone of Gaza strip. RPW is now spread in the whole strip with a high rate of infested palms. The combined high number of weevils and of young palms leads to a very explosive situation.

Control programme is under the management of the Ministry of Agriculture, but with an exceptional and efficient participation of the farmers, and the assistance of various associations and the support of FAO.

As infested palms are present in the Egyptian sector of El-Arich, bordering the southern part of Gaza strip, a programme to obtain the rapid decline of the RPW in the Gaza strip would require the establishment of a buffer zone along the border (Ferry, 2014). New threat exists now from the North as ornamental *Phoenix canariensis* are present in the southwestern part of Israel.

Saudi Arabia

RPW was discovered for the first time in 1987 in Katif. It is considered that it was introduced with ornamental palms.

It is now present in the majority of oasis (Fig. 3).

The present situation is the result of the introduction of new infested palms from abroad and of infested offshoots dispersal, especially from tissue culture palms.

The high number of weevils and the high number of young palms lead to a very explosive situation especially in Qasim and Al Kharj provinces. In Al-Ahsa, thanks to important efforts that have been dedicated for a long time to control the pest, the situation is stabilized but the percentage of infested farms is very high (Ferry *et al.,* 2016).

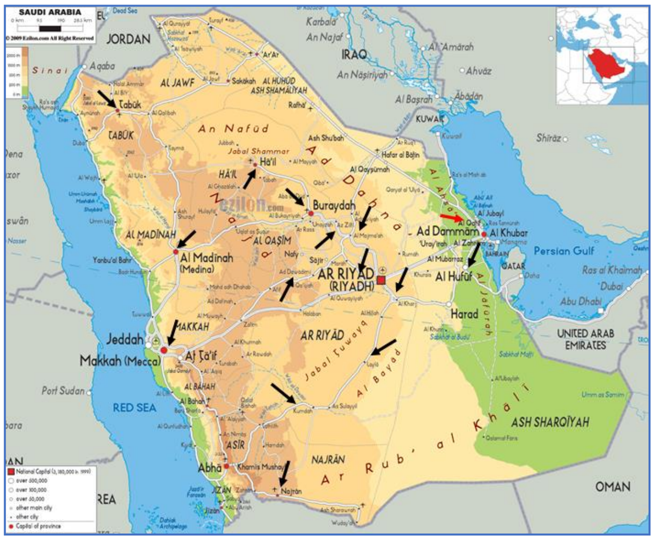

Figure 3. Spread of the red palm weevil in the oasis of Saudi Arabia. The red arrow points to the first discovered spot of Katif.

In KSA, the activities of RPW control programmes are mainly implemented by the Ministry of Agriculture regional authorities. Farmers are little involved, except at the level of some new large farms.

This model of management has not allowed to obtain the eradication of the RPW or even its continuous decline. Very huge resources and budget have been dedicated for numerous years, more than 20 years in Al-Ahsa, to such programmes. They correspond to a scenario that is unsustainable for economic and environment reasons (Ferry *et al.,* in press).

In the framework of the New Saudi Vision 2030 regarding the agriculture sector, new management programmes based on implementing methods and activities to involve much more the farmers have been proposed (Abdedaiem *et al.,* 2017; Ferry *et al.,* 2016).

Oman
The pest was discovered for the first time in august 1993 in the province of Mahda, close to the infested oasis of Al Aïn in the UAE.

It is now present in most of the provinces where date palms are grown.

A task force established by the Ministry of Agriculture has been created to intervene immediately when new infested palms are notified by the farmers. Huge and efficient efforts to inform the people and make them aware of the seriousness of the pest and of the risk presented by the transport of palms have been developed.

Thanks to this policy, the eradication of the RPW has been successful in many provinces. Unfortunately, because of the introduction of new infested palms, several of these places have been re-infested (Ferry, 2012d).

With the one million date palms project, the challenge to prevent re-infestation becomes still more urgent as the young palms are much more susceptible to the pest than the older palms.

United Arab Emirates
It was the first gulf country where RPW was detected in 1985. It is now present in nearly all the oasis and the situation is very critical because millions of palms were planted during the last 30 years. The presence of offshoots and the size of these palms are very favorable to RPW infestation.

Except for some big farms, the RPW control programme is under the entire management of the authorities or of contracted companies.

Qatar, Bahrain, Kuwait, Yemen
The pest was detected in late 80's in Kuwait, in 1989 in Qatar, in 1993 in Bahrain and in 2013 in Yemen.

Until now, no decline of the pest has been obtained in these countries, and the problem is getting worse because new date palms plantations have been established during the last 20 years. No more data available.

Iraq
The pest was detected in October 2015 in Safwan (Basrah region) very close to the border with Kuwait.

Eradication program is going on. As the infested area is still small, quick eradication is perfectly feasible. But, the proximity with infested date palms plantations in Kuwait should lead to the implementation of a regional eradication project.

FAO organized a training of trainers programme in Irak on March 2017. Considering the efficient work that was realized in Safwan since the date of the RPW detection, the on-going programme could perfectly become a success story if strong coordination is implemented with the progamme in Qatar and if FAO could maintain a technical assistance.

In Iraq, new date palms plantations programmes are carried out or planned for the near future. Reinforcement of the regulation (Prohibition of date palm imports), reinforcement of the control at the borders and improved awareness of farmers and other stakeholders should be realized.

Iran
The Pest was detected in Saravan county in 1990, in Nik Shahr and Fanuj in 2012, in Homozgan and Bushehr provinces in 2014, and new detection in Fars province in 2017. The three last detections were linked with the importation of offshoots from Qatar and U.A.E.

No RPW decline was obtained in the oldest infested areas. New infested regions emerged due to inadequate or not rigorously implemented regulations.

Lessons learned

Lesson 1: It is impossible to eradicate this pest if the regulations are not adapted or not applied to avoid imports or within country movements of infested palms
This lesson is evident, nevertheless, in most of the infested countries, the importation of infested palms or the movement of infested palms inside the countries were done in a perfectly regulatory way, in accordance with the quarantine regulations of the countries. These palms were introduced with official phytosanitary certificates and after an official inspection procedure. In the countries where phytosanitary passport were enforced to move the palms, the infested palms were moved and traded with their passport.

Of course, they were imported or moved inside the countries without knowing that they were infested. But, the Phytosanitary Authorities were aware that the palms allowed to be imported or moved were coming from infested countries or regions, and sometimes from very infested places. Unfortunately, they trusted the value of the phytosanitary certificate or they considered that it was possible to inspect efficiently the palms. These views constitute very serious mistakes because it is impossible to detect the eggs or the small larvae that are hidden in the tissue of the palm, so the implementation of an inspection to establish a phytosanitary certificate or to control a palm at the border has no value (Ferry and Gómez, 2002).

In most of the countries, the banning regulation for palms imports or in country movements, when it was taken, was taken very late when the RPW had been already largely spread. Furthermore, in many countries (e.g. in Europe), the quarantine regulations were inapplicable or inefficient to avoid the importation or the movement of infested palms (Ferry and Gómez, 2002; 2013). These regulations were often wrongly elaborated because the phytosanitary authorities tried to avoid a rigorous ban for fear to hamper the import traders and the nursery sector activities.

The ban of importation is not too difficult to be implemented because huge ornamental palms, palms in pots (small palms in pots don't present risk) or batch of offshoots are usually easy to detect at the border. It is thanks to this ban that Algeria is still free of the pest. Unfortunately, in some countries where importation was totally banned (e.g. Tunisia), the RPW was introduced because the regulations were not respected due to the intervention of VIPs.

Another aspect that explains, to a large extent, the failure of regulations respect inside the country is the lack of information. People who need palms seedlings (farmers, landscapers, etc.) ignored generally, and still often ignore, the risk presented by the RPW. They are also totally confident because the provider assures them that the palms are free of the pest as indicated in the phytosanitary certificate or the phytosanitary passport.

Furthermore, the authorities are very often very reluctant to communicate on the presence and the spread of a quarantine pest. Many countries in Europe as in other regions, had, and still have, the tendency to hide this information at the international and also at the local level for various reasons, including political and economic ones. Among many other cases, the information blackout on the RPW problem in Egypt between 1993 and 2000 (Ferry, 1996; Ferry and Gómez, 2002) contributed to the quick spread of the pest in Egypt but also to avoid a palms import ban in the European countries to which hundreds of thousands palms were exported from 2000 to 2007.

The consequences of such behavior are dramatic. Palms owners and palms sector are maintained in the ignorance of the situation instead of being alert and being in position to act to save their palms and to prevent the spread of the pest.

The palms owners are also, sometimes, reluctant to declare that they have found an infested palm for the consequences that can come out of such declaration. To obtain their collaboration in this field and, in the case of the farmers, to obtain a better respect of the ban, it is indispensable to explain to them the challenge of an eradication programme and to implement participatory methods that will facilitate their adhesion to such programme (see lesson 4).

Lesson 2: containment fails if eradication programmes fails

In all the infested countries, RPW containment failed. It failed because to prevent RPW spread outside the infested zones, it is necessary to obtain the quick decline of the pest in these zones and then its eradication.

If, in the infested zones, strong programmes to obtain the rapid decline of the RPW population are not implemented, its population will grow and RPW will look for palms outside the infested zones. A buffer zone will constitute a barrier to prevent its natural spread only if palms are not present in this zone. Otherwise, even if the palms are scattered in this zone and beyond, as the RPW has the capacity to find palms located at some kilometers away from the palm that it has abandoned (personal observation in Elche), its spread will not be stopped if, at enough short distance, there is relay palms where it will breed.

In addition to this natural spreading, must be added the accidental spread that has probably played a more important role than usually consider in RPW dispersal: its accidental transport in vehicles. It is well established, for example, that RPW can move with persons that have handled RPW pheromone diffusers or have been in contact with infested palms. This is why regarding the RPW pheromone handling, it is strongly advised to move the diffusers including the empty ones in closed containers. Transport of fresh cut palm leaves can also contribute to the displacement of RPW which is attracted by the leaf wound smell and will hide between the leaves. Of course, it is also well established that RPW will be very attracted to felled infested palms or portions of infested palms. The transport of such wastes, often to reach a facility that has been created to shred these wastes, has contributed to its dispersal far beyond its natural spreading capacity. It is now strongly recommended to handle all these wastes on the spot (Ferry and Aldobai, in press).

Nevertheless, the main reason of the containment failure has been certainly the transport of palms and offshoots from infested areas to non-infested ones. For all these reasons, it is essential to implement programmes aimed to obtain quickly the decline of RPW to succeed in its containment.

Lesson 3: RPW control programmes based on suppression or on long term eradication objectives are unsustainable.

Figure 4 shows a schematic representation of three different simplified scenarios of RPW control programmes implemented worldwide.

In some places, RPW control programmes have led to the losing race scenario (Fig. 4, left). For these countries, there are two options that represent both a difficult decision:

- either to stop the programmes. In the losing race scenario, an increase of the efforts is figured from year 5. Such increase is useless as it is not sufficient to prevent the exponential growth of the RPW.
- or, if the majority of the main stakeholders are convinced of the interest to save the palms, to conceive them on quite different bases, including especially measures to involve much more the palms owners and their organisations.

In a small group of countries or in some oasis, RPW control programmes have been carried on for many years without obtaining the continuous RPW decline (Fig. 4, center).

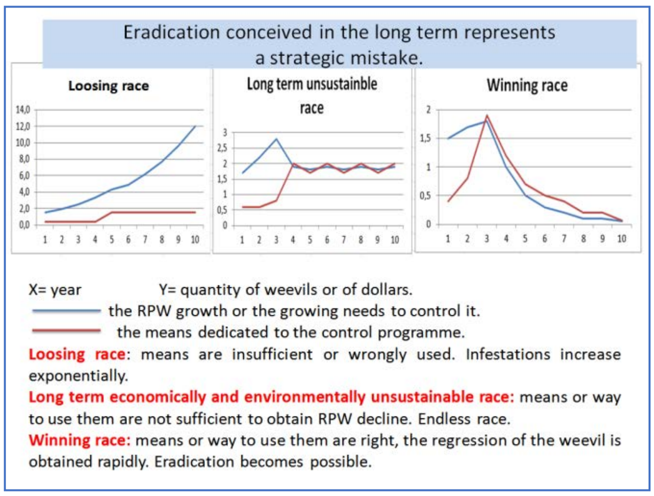

Figure 4. Schematic representation of three different simplified scenarios for RPW control programmes implemented around the world.

These programmes are doomed to fail because they are costly and require permanent activities and vigilance, they don't prevent the progressive loss of palms and RPW spread and they are unsustainable because of the frequent use of insecticides. The two options presented for the previous scenario must be considered. The winning scenario is shown in Figure 4, right.

The rapid decline of the RPW is obtained in few years and then its eradication became quite possible. It is exactly what has been obtained in various oasis in the Middle East (especially in Oman), in Canary Islands or Ceuta in Spain and in Israel (temporally). The success of the corresponding RPW control programmes was mainly based on right organization and management of the programmes, with active participation of the palm owners. When such programmes have to be implemented on large scale, the approach must be to reallocate the means and the activities progressively from the zones where the RPW has been eradicated to the neighboring zones.

An area-wide eradication programme requires for its success to apply participatory methods aimed to mobilize the first concerned stakeholders, the palms owners and their organizations. It requests also a selection of methods affordable and appropriable by the palms owners or their workers themselves, after training farmers trainers or extension agents. All or most of the methods of the IPM strategy that have been applied in the successful programmes to eradicate the RPW can be easily transmitted to the farmers and their workers and applied by them. In a very infested area in South-East France, an eradication programme based on these principles was initiated in 2016. The first results are very promising with a notable decline of the number of new infested palms.

Some entomologists will probably considerer that the success of such programmes is unrealistic. I think that this opinion is due first to a wrong conception of the difficulties. They are not especially linked to the biology of the insect but much more to socio-economic constraints which analysis and methods to overcome them escape generally, and this normal, to the expertise of entomologists. Secondly, the information on the high percentage of success of the eradication programmes is not known as it should be. So, exists often an a priori against the possibility to eradicate a pest. However the percentage of success of the eradication programmes against pests is high. For example, it has been of 76% in the USA for the last 50 years against pests in urban environment, where however such programmes are especially complex to manage (Kean *et al.,* 2019).

Lesson 4: without multidisciplinary and participative approach, eradication programmes are doomed to fail

In the RPW control programs, the role of the palm owners and of their organisations has been dramatically neglected, whereas in fact it is fundamental. A lot of knowledge has been accumulated on the RPW and on the relations between palms and this pest, but very little qualitative and quantitative information is available on the economic consequences of the pest for the palm owners (Figure 5).

Most of the scientists and technicians that have published or are involved in the programmes to control the RPW have been entomologists or plant protection technicians. The number of papers published, even on the economic impact of the RPW at the local or national level, are extremely rare. A much better knowledge on the socio-economic component of the problem is absolutely and urgently indispensable.

As indicated in lesson 3, the involvement of the palm owners and their organizations is a key issue to success of RPW eradication, especially on large scale. Socio-economic experts capable to establish the typology of the different farming systems in relation with the RPW problem and to implement participatory approaches must be part of the RPW control programmes teams.

The failure of the RPW control programmes is not due to the inefficiency of the techniques to control this pest as demonstrated by the projects that have succeeded to eradicate it. The main problem is the extreme high difficulty to apply at a large scale these techniques without the involvement of palm owners and their organizations. If they are involved because socio-economic expertise, efforts and methods are dedicated to this purpose, the panorama becomes totally different.

It is also thanks to such involvement of the palms owners that new technologies adapted to their needs and capacities, which could differ according to the different farming systems, could be usefully developed because conceived with them.

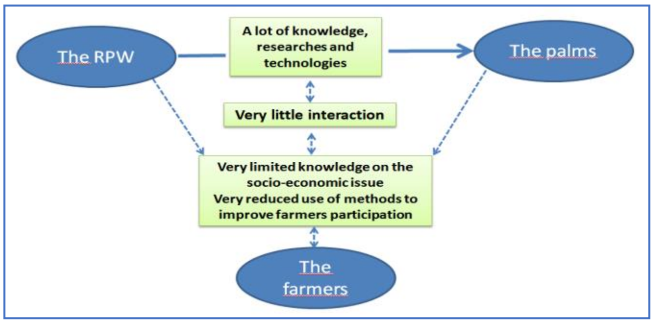

Figure 5. Asymmetric knowledge on the global problem

Lesson 5: eradication of the RPW should not mean automatically the eradication of the infested palms and still less the eradication of the whole infested palms

In the fight against a quarantine organism, eradication of the infested host constitutes a paradigm that is rarely questioned by the phytosanitary authorities. It is usually the first phytosanitary measure adopted, completed often by the eradication also of the non-infested pest host close to the infested one. When alternatives to host eradication exist, this paradigm should be seriously reconsidered, not only because it can be counterproductive, but also because the eradication of the pest's host could lead the pest to spread farther, looking for new hosts.

In the case of the RPW and the date palm, although mechanical or chemical sanitation of infested palms was practiced for a long time, the eradication of the whole infested palms was proposed as the best solution to eradicate the RPW. It was even compulsory, and in some countries it is still the case. Regarding the *Phoenix canariensis* of more than 2-3 m height that are generally infested at the bases of the higher leaves, mechanical sanitation was also developed (Ferry and Gómez, 2008). Nevertheless, two to four years were necessary to obtain the authorization of this technique in Europe. Previously, in all the European countries, it was obliged to systematically eradicate the whole infested palms.

For date palm as well as for *Phoenix canariensis*, this recommendation or obligation to eradicate the whole palm was based on generalized misconception on some important aspects of the RPW biology.

First, it was considered that when a palm was infested, RPW in all its forms and especially the larvae could be present in any part of the palm and accordingly it was preferable to eradicate the whole palm (as if it was contaminated by a microorganism!). This is totally wrong, because in an infested palm, it is very easy and safe to delimitate the parts were the RPW are present, and that usually represent a very small portion of the palms, especially in the large palms or when infestation has been detected early. The eradication of these infested parts is quite sufficient (Ferry and Gómez, 2008; Ferry and Aldobai, in press).

Usually, for date palm, these infested parts are offshoots or portions of the trunk and sometimes bases of the leaves. For *Phoenix canariensis* of less than 2-3 m height, the situation is similar, except of course that they don't have offshoots. For higher *Phoenix canariensis*, the infested parts are the basis of the leaves (except usually the leaves of lower crown) and small portion of the upper part of the trunk.

Secondly, it was considered – and in many places it is still the case - that the wastes after a mechanical sanitation (remaining trunk, leaves) will constitute egg laying sites. It was also considered, that if eggs or larvae were unnoticed in the wastes they will complete in these wastes their cycle and the RPW will continue to breed. These two assertions are wrong because females will not lay their eggs in drying or dead tissue and larvae will not survive in such tissues. For eggs and first larvae instars to survive, they must be placed in living tissue that the RPW females reach by drilling oviposition holes. The larvae, contrary to what is still often assumed, are not xylophagous, they don't ingest the "wood" of the palms; they just chew the fibres and suck the liquid extracted from them. Thus, they can survive outside living tissues.

The risk in the wastes handling is not constituted by the eggs or the larvae but by the adults and the cocoons, that are not too difficult to locate and then eradicate.

Therefore, the handling of the wastes, even for heavily infested palms, is very simple and can be perfectly implemented by a farmer with simple tools or eventually a chain saw (Ferry and Aldobai, in press). For the tall *Phoenix canariensis* that are too heavily infested to be sanitized, it is sufficient to cut the top part of the trunk. The remaining trunk can stay in situ to be handled later like a usual dead trunk. When no intervention is operated on an infested *Phoenix canariensis*, it will die and when all its leaves become dry, it will no more be a RPW breeding spot.

Unfortunately, because of the general misconception previously described, very huge efforts and a lot of time and money have been dedicated to eradicate the whole palms following complex protocols: wrapping the palm, felling the palm, transporting the whole palm, burning the whole palm or burying it or shredding it in huge and very costly machine.

A lot of money and efforts could have been saved if instead of eradicating the whole infested palms, only the infested parts would have considered as the parts to be treated. These reduced parts of the infested palms could have been perfectly handled on the spot with simple tools and methods. In addition, such handling presents the great advantage of not taking the risk to spread the weevil during a transport.

In the Valencia region in Spain, 25 million Euros were spent from 2004 to 2009 in support of the programme to eradicate the weevil. Most of this amount was used to eradicate the whole infested palms. Very little money was available for the other indispensable tasks to succeed the eradication of the pest. Consequently, the RPW continued to spread in the whole region, and, as year after year the budget to dedicate to the eradication of the infested palms continued to increase, the regional plant protection authority decided brutally to abandon the fight in 2009.

Compared with what has been done till now in most of the countries, saving money on the management of the infested palms is easy and will allow to dedicate money, means and efforts to other essential fields.

Lesson 6: The efficient management and monitoring of the RPW eradication programmes request the assistance of a GIS at the local, regional and national level.

It is very surprising to observe that, in nearly all the infested countries, data and maps on the situation and on its evolution, year after year, at the local as well as the regional and national levels, are not available or are poorly documented.

Without this information, continuously updated, it is not possible to know if and where the activities of the program are or are not implemented as planned and where and why they allow or not to obtain the targeted RPW decline. Without this information, it is very difficult to manage efficiently a RPW control programme at the local, regional and national levels

Without this tool, it is not easy to dispose of an efficient early warning system which is essential to obtain the rapid implementation of contingency measures.

Moises Fajardo who was in charge of the eradication programme in the Canary Islands has assured that "RPW eradication in the Canary Islands would have been impossible without GIS" (Fajardo, 2017b).

Conclusions

Important lessons can be drawn from the analysis of the present situation and of the RPW control programmes implemented in the world for the last 30 years. Although the situation is very serious in all the infested countries, it is clear that, on many issues, the programmes can and should be modified rapidly. If it is not done, the palms hecatomb will continue. In the cities, the palms patrimony will disappear completely in the short term. In the oasis, the socio-economic and environmental consequences of the RPW expansion will become really dramatic.

The programmes must be modified, but the objective must also be clearly established. On the basis of the three scenarios corresponding to the evolution of the situation for the last thirty years presented in this paper, the objective must be clearly to obtain the rapid decline of the pest in pilot areas. From these initial zones, this strategy will be progressively implemented to larger and larger areas.

As the infestation concerns now very wide areas, the participation of the palms owners and their organizations is indispensable. Till now, very little efforts and methods have been dedicated to obtain the participation of these essential actors, because it was considered that it was useless and because no socio-economists with expertise in participatory approach and farming systems analysis were involved in the RPW control programmes. The problem of the RPW was only considered from the technical point of view. Which technique, which product, which equipment, which regulation? The socio-economic dimension of the problem was not considered, as demonstrated by the nearly total lack of data in this field. On the human and social issue, the first concerned actors, the palms owners and their organization were barely consulted and involved in the conception and implementation of the programmes.

In date producing countries, the farming systems are diverse. To simplify the situation, they can be divided into few groups: the traditional farming systems and the "modern" large great plantations. Regarding the traditional farming systems themselves, they can be of quite different types: the farms in which date production constitutes an important source of income for the palm owners and the farms that have mainly a recreational and societal vocation for their owners.

The solutions to propose and to discuss with the farmers will have to take into consideration these different farming systems. Nevertheless, as the RPW ignores these differences (except that they can have agronomic consequences that will interfere with its behavior), the success of its control in the large farms depends on its success in the traditional farms.

الملخص

فيري، ميشيل. 2019. الحالة الراهنة والدروس المستفادة من ثلاثين سنة من الكفاح إزاء سوسة النخيل الحمراء. مجلة وقاية النبات العربية، 37(2): 109-118.

لقد أدّت حركة الاستيراد الخارجي والتداول الداخلي لأشجار/فسائل النخيل المصابة إلى إدخال وانتشار سوسة النخيل الحمراء في كامل بلدان منطقة الشرق الأدنى وشمال أفريقيا (باستثناء الجزائر والسودان) وكذلك في دول الساحل الشمالي لحوض البحر الأبيض المتوسط؛ وقد جرت هذه الحركة والتداول بشكلٍ رسمي. ففي منطقة حوض المتوسط، جرى استيراد مئات الآلاف من نخيل الزينة من جمهورية مصر ما بين عامي 2000 و2007. فشلت جميع البرامج في مكافحة هذه الآفة ضمن جميع الدول الموبوءة بها، ويزداد الوضع الحالي تحت وطأة خطرٍ كبير بسبب آثاره الاجتماعية-الاقتصادية في الدول المنتجة للتمور فضلاً عن تشويه كبير للمنظر الطبيعي في تلك الأماكن التي يزرع فيها النخيل لأغراض الزينة. ولاقتراح حلولٍ سليمةٍ ومستدامةٍ لمكافحة هذه الآفة الخطرة فإنّه لابدّ من استخلاص العبر سواءً من حالات الفشل الرائجة على نطاقٍ واسع، أو تلك الحالات القليلة التي تستحق نجاح المكافحة هذه الآفة. وتنضوي هذه الدروس الرئيسة على: (أ) يجب حظر استيراد وتداول النخيل عند عدم إيجاد طرق دقيقة لفحص الفسائل عن وضع سريع للتعرف على الحشرات؛ (ب) إن استراتيجية احتواء الآفة مصحوبة بالفشل مالم تقترن مع برامج ناجعة مطبّقة لتحقيق فحص سريع لتحديد سوسة النخيل الحمراء؛ (ج) إنّ تصوّر استئصال الآفة كهدف بعيد المدى يعدّ خطأً استراتيجياً؛ (د) يمكن استئصال الآفة بوجود الأدوات المتاحة حالياً؛ (هـ) يعدّ النموذج القائل بأنّ استئصال الآفة يعني الاستئصال التلقائي لأشجار النخيل المصابة أمراً خاطئاً؛ (و) ليست المشكلة الرئيسية مسألة تقنية ولكنّها اجتماعية-اقتصادية وتنظيمية؛ (ز) يجب اقتراح دراسات اجتماعية-اقتصادية على نحوٍ عاجل، كما يجب تطبيق النهج التشاركي لدمج مالكي النخيل ومنظماتهم على نطاقٍ واسع ضمن برامج الفحص السريع والاستئصال لسوسة النخيل الحمراء.

كلمات مفتاحية: *Rhynchophorus ferrugineus*، *Phoenix dactylifera*، *Phoenix canariensis*، سوق نخيل الزينة، استقصاء، الفحص السريع، احتواء، منطقة الشرق الأدنى وشمال أفريقيا، منطقة حوض المتوسط، اجتماعية-اقتصادية، لائحة صحية نباتية، إجراءات صحية، إدارة، نهج تشاركي، المكافحة المتكاملة.

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Studies on curative treatment of red palm weevil, *Rhynchophorus ferrugineus* Olivier infested date palms based on an innovative fumigation technique

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Abstract

Al Ballaa S.R. and J.R. Faleiro. 2019. Studies on curative treatment of red palm weevil, *Rhynchophorus ferrugineus* Olivier infested date palms based on an innovative fumigation technique. Arab Journal of Plant Protection, 37(2): 119-123.

The Red Palm Weevil (RPW) *Rhynchophorus ferrugineus* Olivier (Coleoptera: Curculionidae) is a key pest of date palm *Phoenix dactylifera* L. in the Near East and North Africa region. RPW infested date palms respond to curative chemical treatments if detected and judiciously treated in the early stage of attack. However, the currently used curative treatments, involve either excessive tissue removal of the palm around the infested palm section (mechanical sanitization) making the palm weak and vulnerable to toppling, injecting insecticide into the infested palms which often does not kill all the stages of the pest within the palm, calling for repeated applications or fumigating the infested palm section with phosphine gas which is also not always effective, possibly due to inadequate dose and escape of the gas. A new fumigation technique involving treatment of infested date palms with aluminium phosphide tablets (3g) ensuring complete entrapment of phosphine gas was devised and field tested in 295 RPW infested date palms in various stages of attack in Al-Qassim, Kingdom of Saudi Arabia, during 2017-2018. The technique was tested in both young date palms (9-12 years old) as well in offshoots (4 years old), through a series of field trials to optimize the number of applications, dose, duration of treatment and type of wrapping to entrap the gas. Results revealed that for young date palms in the susceptible age of attack to RPW, a single application of 10 aluminium phosphide tablets for 5 days inserted in air tight black plastic wrapping resulted in complete mortality of larva, pupae and adult stages of the pest. Further, in offshoots, a single treatment with 15 aluminium phosphide tablets inserted in air tight transparent plastic wrapping for 10 days ensured complete mortality of the pest within the palm. The technique can be used for both field treatment of infested palms as well for quarantine treatment of date palm offshoots and is gaining popularity in Saudi Arabia.

Keywords: Saudi Arabia, offshoots, aluminium phosphide, quarantine, curative treatment.

Introduction

The Red Palm Weevil (RPW) *Rhynchophorus ferrugineus* Olivier (Coleoptera: Curculionidae) is a key pest of date palm *Phoenix dactylifera* L. (Faleiro, 2006). RPW is native to South and South-East Asia where it is a major pest of coconut *Cocos nucifera*. After gaining foot hold on date palm in the mid-1980s the pest spread to the Middle-East, North Africa and the Mediterranean basin countries mainly through infested planting material transported for agricultural and ornamental gardening, calling for strict pre- and post-entry quarantine regimes.

The pest is reported to attack 40 palm species in diverse agro-ecosystems worldwide (Giblin-Davis *et al*., 2013) and likely to expand its geographical range (Fiaboe *et al*., 2012). Most recent introductions of RPW are from Abkhazia in the Republic of Georgia and in Djibouti in East Africa (Faleiro *et al*., 2018). Palm weevils threaten agricultural (date plantations) and natural areas (palm oases) (Milosavljević, 2018).

RPW is an internal tissue borer that is difficult to detect. Palms in the late stage of attack exhibit extensive tissue damage due to larval feeding. Such palms harbour several overlapping generations of RPW and are beyond any curative treatment. These palms have to be eradicated. RPW infested date palms respond to curative chemical treatments if detected and judiciously treated in the early stage of attack (Abraham *et al*., 1998). However, the currently used curative treatments, involve either excessive tissue removal of the palm around the infested palm section (mechanical sanitization) often making the palm weak and vulnerable to toppling, injecting insecticide into the infested palms which always does not kill all the stages of the pest within the palm, calling for repeated applications or fumigating the infested palm section with phosphine gas which is also not always effective due to inadequate dose and escape of the gas.

Insecticide applications are, at present, the most effective method for protecting palms from attack by palm weevils (Milosavljević, 2018). Although, curative treatments of RPW infested date palms using aluminium phosphide is widely practiced in UAE and the state of Bahrain, there is no information on the dose and duration of treatment using aluminium phosphide to safely and effectively treat RPW infested date palms.

In this study, treatment of RPW infested date palms with aluminium phosphide tablets was extensively evaluated in the Kingdom of Saudi Arabia with an objective to standardise the dose and duration of treatment for its safe and effective use. The protocols adopted and results obtained are presented below.

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Materials and Methods

During the end of 2017 and early 2018, a series of field experiments were conducted by Rasheed Mohammed Al Ballaa and Munira Mohammed Al-Hothaili Endowment fund (May the Mercy of Allah be upon them) in Al-Qassim region of Saudi Arabia, with an aim to develop an effective, low-cost and easy to apply curative treatment method to control the RPW in infested palm trees using aluminium phosphide. The trials were based on the hypothesis that RPW needs oxygen to survive, air reaches RPW stages within the palm tree through the feeding tunnels cavities, the tunnels are connected to outside air and can be used to deliver fumigants. Keeping this in view a new fumigation protocol involving treatment of infested date palms with aluminium phosphide tablets (3 g, 50-60% a.i.) ensuring complete entrapment of phosphine gas was devised and field tested in over 400 infested palms including 295 RPW infested date palms in various stages of attack reported under this study. Material and apparatus used to assemble a gas entrapment chamber on the infested palm is depicted in figure 1. The technique was tested in both young date palms (9-12 years old) as well in offshoots (4 years old), through a series of field trials to optimize the number of applications, dose, duration of treatment and type of wrapping to entrap the gas.

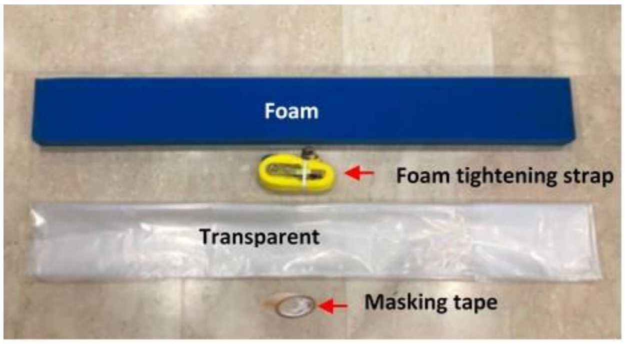

Figure 1. Material and apparatus used to assemble a gas entrapment cylinder/chamber on the RPW infested palm.

The treatments tested are presented in Table 1. Entrapment of the phosphine gas around the infested site on the palm (usually the trunk) was ensured by securing a plastic wrap (4 meters long, 2.5 meters wide, 150 microns thick) on two foam pieces (toluene diisocyanate foam) encircling the palm above and below the infested site. The foam pieces were secured around the palm trunk initially by using an adhesive tape. Aluminium phosphide tablets were placed on the palm trunk around the infested site as per the treatment schedule mentioned in table 1. Subsequently, the plastic wrap was fastened to the foam at both the ends using masking tape, which was also used to seal both the longitudinal ends of the plastic wrap then the tightening strap was applied on the middle of the width of the two foams and tightened to the maximum limit using the mechanical tightening apparatus (Figure 2). Detailed treatment protocol is presented in table 2.

In treatment one, were 20 tablets were applied for 10 days in three splits of 10, 5 and 5 at 1,3 & 6 days, respectively application at 3 and 6 days was made by making a small slit on the wrap and sealing it with masking tape immediately upon inserting the tablets. In treatment five of this study, black plastic wrap was used to assess its impact on treatment duration.

Upon completion of the treatment duration, the plastic enclosure was removed and all treated palms were manually scrapped to remove the dead palm tissue and count the dead and live stages of the pest including larvae, pupae and adults. Data on pest mortality (%) was subjected to statistical analysis (ANOVA where treatment means were separated using DUNCAN's Multiple Range Test). Phosphine gas levels (ppm) were also measured inside the gas entrapment cylinder on the palm and also outside the treated palm between 6 to 96 hours after treatment, using gas alert extreme a portable phosphine gas detector. Results of the study are presented and discussed below.

Table 1. Aluminium phosphide treatment imposed in RPW infested date palms

Treatment*	Number of Palms Treated	Severity of Infestation	Distance of infestation from ground (cm)	Average age of treated palm (years)
T 1	100	mild to severe	40-90	12
T2	50	mild to severe	40-80	12
T3	50	mild to severe	40-80	12
T4	25	mild to severe	40-80	12
T5	50	mild to severe	10-60	6
T6	10	mild to severe	40-80	12
T7	10	mild to severe	40-80	12

* T1: 20 Tablets for 10 days applied in 3 Splits of 10,5 & 5 at 1,3 & 6 Days, respectively [Transparent Plastic Wrap];
T2:15 Tablets for 10 days [Transparent Plastic Wrap];
T3:15 Tablets for 5 days [Transparent Plastic Wrap];
T4:10 Tablets for 10 days [Transparent Plastic Wrap];
T5:10 Tablets for 5 days [Black plastic wrap];
T6: 5 Tablets for 10days [Transparent Plastic Wrap];
T7: Control [No Treatment]

The above treatments were administered by staff using all protective gear including, hand gloves, nasal mask, eye goggles and safety shoes.

Table 2. Protocol adopted to treat RPW infested date palms with aluminium phosphide

• Grass/weeds around the trunk of the palm were removed.
• The trunk of the palm was pruned very short to have maximum 5 cm frond base using a manual or automatic saw so as to remove any palm parts that may puncture the plastic. Note: There is no need to clean the site of the infestation on the palm and remove the insect stages
• Two pieces of foam were carefully installed around the trunk of the palm so that the first was at a level of about 1.25 meters above entry site of the pest and the second at a level of about 1.25m below entry site or at the level of the soil surface if the infestation site was low, and held the foam in place using the adhesive masking tape
• Aluminum phosphide tablets were placed around the trunk of the palm as per the treatment schedule presented above in table 1 near the entry site. (aluminum phosphide tablets usually start emitting toxic phosphine gas not less than 1 hour after exposure to air).
• The plastic sheet was placed neatly and quickly around the trunk of the palm so that it became two continuous layers of plastic around the trunk and was fixed in place using the adhesive masking tape.
• The tightening belt (strap) was placed on the plastic sheet on the middle of the width of the foam. The belt was then tightened so that the tightening strength reaches maximum to prevent phosphine gas from escaping.
• The tightening belt was also placed around the plastic sheet on the middle of bottom foam and the belt was tightened in the manner described above.
• Soil was placed above the bottom of plastic sheet and the soil was compacted
• On completion of the treatment duration the plastic sheet was removed quietly and carefully after removing the tightening belts from the top and bottom. The plastic sheet and belt can be used again several times provided it is not punctured

Figure 2. Foam (A) and plastic wrap (B) around the infested site on the palm ensuring complete entrapment of the phosphine gas

Results and Discussion

Results presented in table 3 indicate that the treatment means were highly significant ($p < 0.0001$) indicating that aluminium phosphide treatment of RPW infested palms is very effective in killing the hidden stages of the pest. However, what is required is to use the minimum dose for the shortest possible time to obtain 100% mortality. Although the first three treatments resulted in 100% mortality of all the three stages of the pest, either the dose or the duration were on the higher side. In an effort to reduce the number of tablets used (dose/palm) and duration to treat an infested palm,10 aluminium phosphide tablets for 10 days in transparent plastic wrap (T4) was not satisfactory as this resulted in several live stages of the pest (Table 3 and Figure 3). Also, in T6 (5 tablets for 10 days with transparent plastic wrap), live stages of the pest were detected. However, in T5, when 10 tablets were used for 5 days in black plastic wrap, 100 % mortality of the larval, pupal and adult stages was obtained (table 3 and figure 3). It can be inferred that the black plastic wrap made the difference resulting in 100 % mortality probably due to the longer half-life for phosphine gas in absence of exposure to light, allowing for higher phosphine gas level maintained for longer time

Table 3. Mortality of different stages of RPW in date palm treated with aluminum phosphide

Treatment Name*	% Mortality ** Adults	Larvae	Pupae	Number of insect stages dead/live
T1	100.00 A	100.00 A	100.00 A	5215/0
T2	100.00 A	100.00 A	100.00 A	2007/0
T3	100.00 A	100.00 A	100.00 A	2115/0
T4	94.00 B	99.50 A	96.00 B	787/8
T5	100.00 A	100.00 A	100.00 A	2185/0
T6	76.55 C	67.02 B	100.00 A	543/108
T7	0.00 D	0.00 C	0.00 C	0/100
p-Value	<0.0001	<0.0001	<0.0001	
CV (%)	7.59	5.53	6.00	

* T1: 20 Tablets for 10 days applied in 3 Splits of 10,5 & 5 at 1,3 & 6 Days, respectively [Transparent Plastic Wrap]
T2:15 Tablets for 10 days [Transparent Plastic Wrap]
T3:15 Tablets for 5 days [Transparent Plastic Wrap]
T4:10 Tablets for 10 days [Transparent Plastic Wrap]
T5:10 Tablets for 5 days [Black plastic wrap]
T6: 5 Tablets for 10days [Transparent Plastic Wrap]
T7: Control [No Treatment]
** Means with at least one letter common are not statistically significant using DUNCAN's Multiple Range Test.

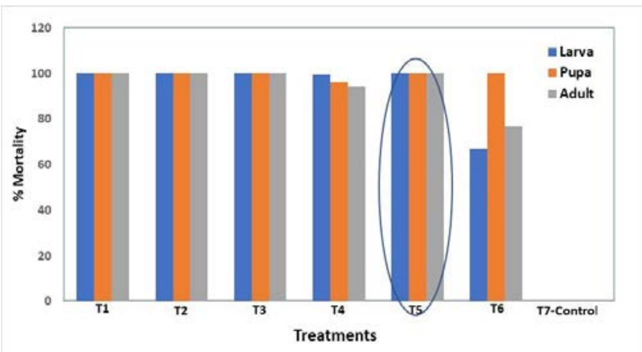

Figure 3. Mortality (%) of RPW in infested palms treated with aluminum phosphide. T1: 20 Tablets for 10 days applied in 3 Splits of 10,5 & 5 at 1,3 & 6 days, respectively [transparent plastic wrap]; T2: 15 Tablets for 10 days [transparent plastic wrap]; T3: 15 Tablets for 5 days [transparent plastic wrap]; T4: 10 Tablets for 10 days [transparent plastic wrap]; T5: 10 Tablets for 5 days [black plastic wrap]; T6: 5 Tablets for 10days [transparent plastic wrap]; T7: Control [No Treatment]

Aluminum phosphide treatment of RPW infested coconut palms has been practiced since long and in date palms it is extensively practiced in UAE and Bahrain. 1-2 aluminum phosphide tablets have been used to cure RPW infested coconut and date palms (Lakshmanan *et al.*, 1972; Subba Rao *et al.*, 1973; Vidyasagar *et al.*, 2000). However, there is no data on the duration of treatment and the precise protocol adopted to ensure that there is no escape of phosphine gas after treatment. Furthermore, inadequate sealing of the infested site on the palms results in escape of the phosphine gas. Our studies using a portable phosphine gas detector (GasAlert Extreme) revealed the detection of high levels of phosphine gas outside the plastic wrap for up to 36 hours after treatment in infested palms treated by the old method, this finding may contribute to the limited effectiveness of the old method. In palms treated by the method developed in this study no phosphine gas was detected outside the palm, while therapeutic levels of phosphine gas were detected inside the plastic wrap up to 7 days after treatment ensuring complete mortality of all pest stages.

Inappropriate treatments with aluminium phosphide could lead to enhanced levels of resistance. Studies carried out in Pakistan recorded high, Resistance Ratios (RRs) ranging from 63 to79 fold for phosphine (Wakil *et al*., 2018). This could lead to reduced effectiveness of the chemical. Studies carried out in Spain in *P. canariensis* suggest that a dose of 1.14 g aluminium phosphide/m3 for 3 days is enough to kill all the stages of RPW in an infested palm tree, and is recommended as a quarantine protocol provided the dose is not phytotoxic to the treated palms (Llácer and Jacas 2010).

Conclusion

Treatment of RPW infested date palms in the susceptible age group of less than 15 years with 10 tablets of aluminum phosphide for 5 days in air tight black plastic wrap ensures 100 % mortality of the larval, pupal and adult stages of the pest and is a cost effective, safe and easy method that can be adopted as a curative treatment in date palm. The technique is gaining popularity in Saudi Arabia. The method could form the basis of developing quarantine treatment of date palm offshoots.

الملخص

بلاعي، صلاح وجورج رويمن وفلايرو. 2019. دراسة تأثير مع ملت اعلجي ة لمل فح سوسة النخيل الحمراء *Rhynchophorus ferrugineus* Olivier في نخيل الات مربا عتمالق ن يمقبتكرة للنخيل. مجلة وقاية النبات العربية، 37(2): 119-123.

تعد سوسة النخيل الحمراء *Rhynchophorus ferrugineus* Olivier (رتبة غمديات الأجنحة Coleoptera، فصيلة Curculionidae) من أخطر الآفات الحشرية التي تصيب نخيل التمر *Phoenix dactylifera* L. في العالم وخاصة في منطقة الشرق الأدنى. وتشمل طرق مكافحة هذه الحشرة الإجراءات التالية: 1) الكشف المبكر عن الإصابة ومعالجتها، 2) تطبيق ممارسات زراعية سليمة، 3) المكافحة الكيميائية. ... 2018/2017. ... 10 ... 5 ... 15 ... 10 ...

كلمات مفتاحية: المكافحة الكيميائية، سوسة النخيل الحمراء، نخيل التمر.

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A simple and low cost injection technique to protect efficiently ornamental Phoenix against the red palm weevil during one year

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Abstract

Gomez, S. and M. Ferry. 2019. A simple and low cost injection technique to protect efficiently ornamental Phoenix against the red palm weevil during one year. Arab Journal of Plant Protection, 37(2): 124-129.

Preventive injection treatments in the framework of IPM programs to control the RPW in ornamental palms can present the great advantage to protect them for a long period, but also to transform them in deadly traps for the new weevil generations, contributing thus greatly to the decline of the RPW population. But for the preventive treatments as well as for the other components of the RPW control programmes, it is now essential, given the widespread and abundance of the pest, to propose simple to apply and low cost but also efficient and safe technologies. In this study, a very simple technique was developed based on an infusion process to inject an emamectin benzoate (EMA) formulation, at 3,5% concentration. The results showed excellent efficiency under different experimental conditions. For the palms of more than 8 meters height, 100% of the larvae were killed even 360 days after injection, compared to 11% in the control treatment.

Keywords: Control, injection, emamectin benzoate, RPW.

Introduction

The red palm weevil (RPW) *Rhynchophorus ferrugineus* Olivier is a phytophagous insect. Its larvae chew the fiber of the internal tissues of palms organs for sucking its sap and dig galleries that are transformed with time to big holes. Such damages are often accompanied with micro-organisms infections that contribute to the death of the palms.

In an infested palm, all the stages of the RPW can be found. In mature and tall palms, infestation starts generally at the base of the leaves base of the inner and middle crowns. Females slip as low as possible between these leaves and dig a small cavity where they lay their eggs. Contrary to what is mentioned for a long time, previous wounds are not necessary for oviposition (ferry and Gomez, 2015). After hatching, the larvae feed, grow and dig galleries, rarely upwards, inside the leaves. After several moults, they migrate close to the leave surface where they form a cocoon with an opening to the outside to allow the exit of the adult. During the second reproduction cycle, the females will most often use the openings and galleries previously made by the larvae to lay their eggs. During the second and following cycles, larvae tend to colonize the leaves bases of the middle crown rather than the central leaves (Ferry and Gomez, 2008).

For RPW control, preventive treatments are mostly applied by soaking abundantly the bases of the leaves each 3-4 weeks. In France, preventive treatments based only on chemical products (excluding neonicotinoids that are now forbidden since September 2018) or alternating chemical products and nematodes are compulsory on all the palms located in the infested areas (Ministère de l'Agriculture, 2010). The application of these treatments is unsustainable in the medium term for economic reasons but also for the risks such chemical treatments impose on health and environment (Ferry *et al.,* 2018).

The use of injection techniques to apply chemical insecticides against the RPW not only can reduce substantially the pollution caused by the traditional treatments (by avoiding environment dispersal when treating, by confining the insecticide into the palm tissue, by reducing the quantity chemical and the number of applications) but also by being more efficient against the RPW, because especially of its capacity to reach the larvae.

The injection of various substances in trees has been implemented for very long time, at least as far as the Hellenistic period. Its use for plant health purpose goes back essentially to the middle of twentieth century, and an important development in with the spread of systemic insecticides in the 70s. The technique triggered numerous investigations and applications that gave place to an important literature (Ferry and Gomez, 2014).

For more than thirty years, injection treatments were applied with success against different serious pests and diseases in oil palms and coconuts plantations in Asia, Latin America and Africa as well as against the RPW on date palm and coconut plantations (Aldawood *et al.,* 2013; El-Ezaby, 1997; Faleiro, 2006; Wood, 1974; Nadarajan *et al.,* 1981). But they have been mainly used as curative treatments. To control RPW in Phoenix canariensis, this technique is in use for around 15 years in the south of Spain (Hernandez-Marante *et al.,* 2003). In Florida, injection technique is allowed and used to fight against the Lethal Yellowing and the new LPD disease that affect several palm species (Tomlinson, 1990). The opposition sometimes raised against injection in palms was and is still based on frequent serious mistakes committed regarding palms biology, as well as on insufficient knowledge of the existing literature and practices regarding the use of this technique in the world. This

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technique if well applied is obviously of great interest for palms treatments against various pests and diseases.

Thanks to this numerous interconnections (Tomlinson, 1990), even with a small number of injection points, the dispersal of injected insecticides will be excellent at the top of the palm tree. This dispersal is optimum to control a pest like the RPW whose preferential egg laying sites, for the palms without offshoots, are the spear leaves and the leaves of the inner crown. For palms with offshoots, like date palms, injection must be applied as low as possible to allow the insecticide migration, principally acropetally in the stipe through the xylem sap, and, for some insecticides and in lower quantity basipetally through the phloem sap (Ferry and Gomez, 2014).

The success of integrated eradication programs for RPW implies the engagement of important measures and means. Consequently, the programs must be conceived to reach the objective as quickly as possible. The realization of preventive treatments of all palms of the potentially infested zones (100 to 1000 meters around an infested palm or of a trap that has captured RPW) that constitutes an essential component of an integrated program of eradication requires important efforts regarding organization and means (Paz *et al.,* 2010). The use of methods which permit the significative reduction of such effort is indispensable to make such programs acceptable and leads to their successful implementation.

The aim of this research is to identify insecticides with long persistence and injection methods easy and not expensive to apply.

Materials and Methods

For the assessment of injected insecticide effectiveness and persistence, a bio-essay method (Estevez *et al.,* 2011, Gomez *et al.,* 2011) was elaborated. It presents important advantages compared with usual methods. One of the classical methods is based on comparing the health status between treated and untreated palms; it requires to dispose of a large number of palms in the field for robust statistic. A second method requires to sacrifice palms to evaluate larvae mortality. A third one is based on determining the active insecticide residues content.

The method that we elaborated is based on harvesting, at selected intervals of time, the target organs of the treated palms (leaves of adult palms or offshoots) and to feed the RPW larvae with them by introducing the larvae into the tissues of these target organs. They were then maintained in a chamber with controlled conditions with appropriate humidity for several days. Finally, they were dissected to evaluate with high reliability if the insecticide is present at sufficient concentration to kill the larvae. This method is incomparably easier to use than the two first methods previously quoted. In relation to the third method mentioned above, our method allows avoiding erroneous interpretations that can lead to conclude that an insecticide doesn't move or is no more efficient because the active ingredient residue was not detected or present at a very low level, when in fact it has been metabolized to another form also effective against the pest (Gomez and Ferry, 2015).

The insecticide

The palms were injected with a solution of emamectin benzoate 3,5% (EMA).

Emamectin benzoate is an avermectin class insecticide developed for the control of lepidopteron insects. This class of pesticide consists of homologous semi-synthetic macrolides that are derived from the natural fermentation products of Streptomyces bacteria. It kills insects by disrupting neurotransmitters, causing irreversible paralysis. It is more effective when ingested, but it also somewhat effective by contact. Target pests are numerous. For the proposed use in tree injection, the target pests include mature and immature arthropod pests. It is lethal upon ingestion or direct contact.

Anses (2014) considered that the injection of EMA formulation does not present risks or presents acceptable risks on the following issues: for the operator and the consumer when applied on ornamental palms; on environment organisms; of water contamination; on bees when palms are not producing nectar, which is the case of *Phoenix canariensis*.

The palms

Two groups of *Phoenix canariensis* were selected for the trials: (1) 24 palms of 3 meters stipe height situated in a parcel in the countryside of the Elche palm grove, Alicante: 38º 13’ 27’’ N, 0º 41’ 43’’ W, (Figure 1); (2) 8 palms of more than 8 meters stipe height situated in a garden in Aspe, Alicante: 38º 20’ 49.65’’N, 0º 40’ 2.76’’W, (Figure 1).

Trials

Trial 1. Height. One of the counterarguments against the use of injections in palms is that the product will never be able to reach the top of very tall palms when injected at the base of the stipe. We have compared the efficiency and persistency of EMA injected in Palms of more than 8 m versus palms of 3 m height.

Replicates: 4 palms of more than 8 m height in public garden conditions compared with 4 treated palms of 3 m height. Four non-treated palms constituted the control palms of this trial. Number of evaluations were six: 15, 30, 60, 90, 180 and 360 days after treatment.

Trial 2. Another counterargument is that the injected product only could translocate in the palm when the plant is well irrigated. Accordingly, efficiency and persistency of EMA injected in irrigated versus non-irrigated palms were compared.

Replicates: 4 treated and 4 control palms (non-treated) in irrigated conditions (every month by flood irrigation) versus 4 treated and 4 control palms in non-irrigated conditions and in a location with no water table. Evaluation was made four times, 30, 90, 180, 360 days after treatment.

Trial 3. Dose response: three different doses of EMA 3,5% (25 ml, 50 ml or 100 ml of undiluted product). Replicates: 4 palms for each treatment in irrigated conditions. 4 control palms in irrigated conditions. Evaluation was made four times, 30, 90, 180, 360 days after treatment.

Figure 1. (A) 3 m canary; (B) More that 8m canary palms

Injection method

For the injection method, we were looking for the simplest, cheapest and safest one. We tested different techniques and we developed a method of injection by infusion that gathered all these qualities. Preliminary trials demonstrated that it was at least as efficient as the other techniques.

The palms were treated once with undiluted product, simply poured in 4 holes drilled at breast heigh in the trunk of each palm, 50 ml of EMA 3.5 % for trials 1 and 2, and the correspondent doses for trial 3. The size of the holes was proportional to the different doses tested (Figure 2).

Figure 2. Method of injection

Evaluation

At different intervals of time, during one year, from each palm, two fronds of the central crown and one spear frond were cut untill their base. Such base constitute for the RPW female the usual target for ovoposition in *Phoenix canariensis*.

Bioassays were made in the laboratory (Figure 3): at the base of each frond, 3-4 small holes were drilled in which the larvae. One larva of 1 to 2 g was placed in each hole. 15 days later, the status of the larvae was observed and the still alive larvae were transferred individually to containers containing artificial diet, and frequently observed for 15 days. The same procedure was adopted for the control palms. The larvae were obtained from the rearing unit in our laboratory, using adults captured weekly in the traps placed in an RPW infested area.

Figure 3. The bioassays

Residue analysis

A 50 g sample of each of the leaves bases of trial 3 was taken and sent to the laboratory of the University of Cordoba, Spain, to analyse for the EMA content. Regarding our method concerning residue analysis, Dembilio *et al.*(2015) argued that our results with this method had to be considered with precaution because the accumulation of active material could also take place in other portions of the leaves and even of the palms. However, what really counted in our research was that the concentration of the active material at the basis of the leaves where the oviposition takes place should be sufficient to kill the larvae and protect the palm.

Phytotoxicity

The palms treated at the dose of 100 ml were dissected after the last evaluation to control the right compartmentalization of the drilling wounds and an eventual phytotoxicity.

Results and Discussion

The results showed high efficiency under the different tested conditions. High larvae mortality rate was found (always more than 86% and 100% with the tall palms) during a year period in all treated palms. Very few larvae survived after feeding in the leaves of the treated palms. Moreover, the majority of these larvae died few days after being fed on artificial diet.

For the palms of more than 8 meters high, 100% of the larvae were killed even in the leaves harvested 360 days after injection (when the average larval mortality rate of the control was 11%). With these tall palms, the results were even better than the best results obtained with the palms of 3 m height (Figure 4). These results showed that the height of the palms is not a handicap for this technique.

No significant differences were found between larvae mortality rates in trial 2, when irrigated and non-irrigated palms were compared. Such results suggest that a good level of translocation of the injected chemical occurred even under dry conditions (Figure 5). The same effect was obtained in the trial with different doses, since no significant differences were observed. Only at 360 days, a decrease in all doses was noted (Figure 6).

As for the control (un-treated palms), the mortality of the larvae in the leaves was significantly less (Figure 7) indicating the reliability of the test.

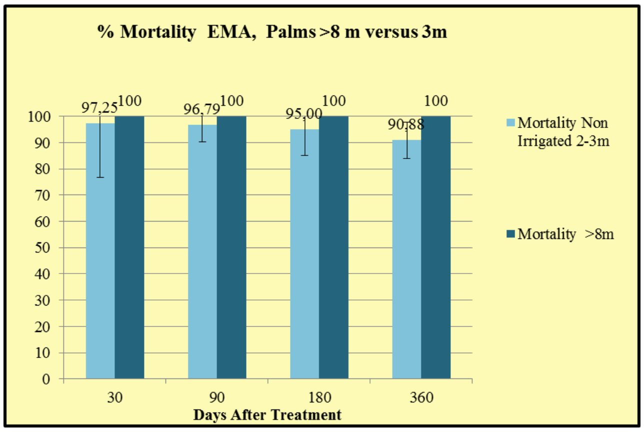

Figure 4. Mortality rate (%) of larvae feeding in leaves of treated palms (8 m and 3 m palms).

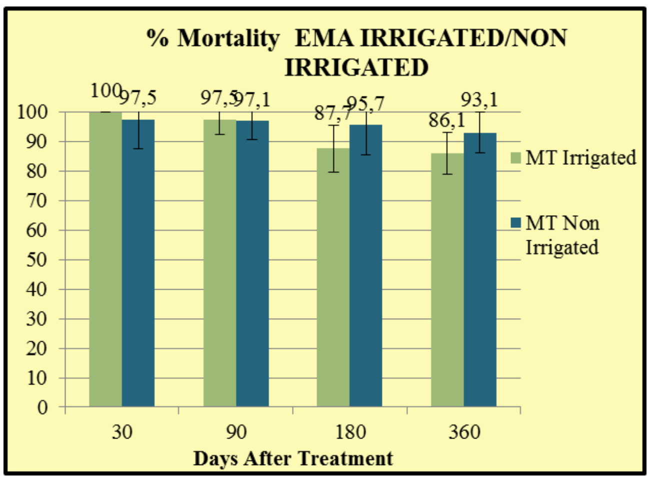

Figure 5. Mortality rate (%) of larvae in irrigated and non-irrigated palms treated with EMA.

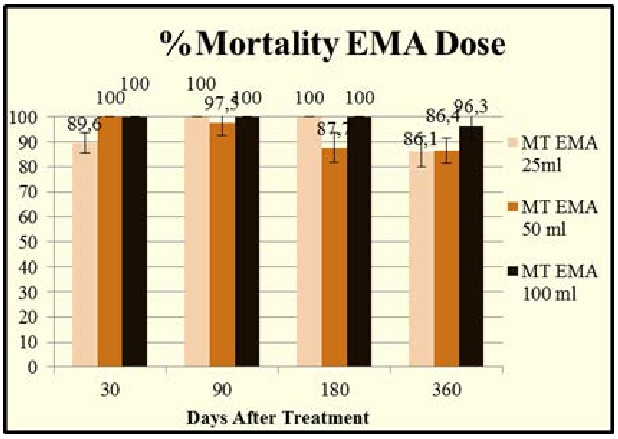

Figure 6. % mortality in larvae injecting doses of 25ml, 50ml and 100ml

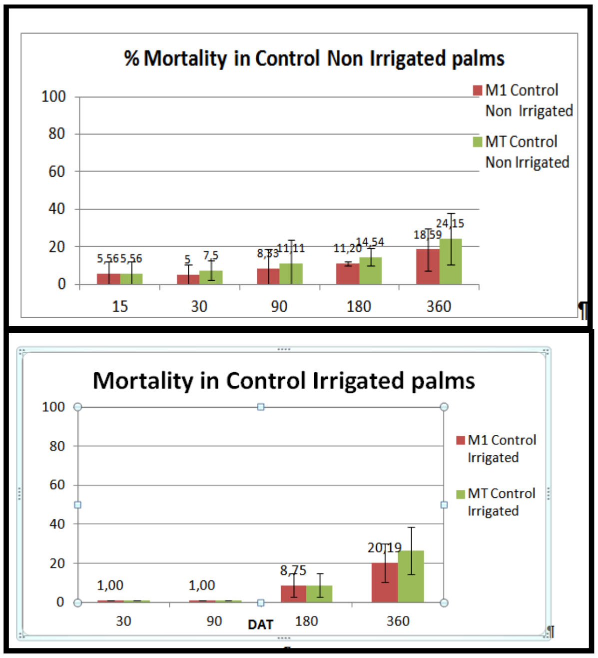

Figure 7. Larvae mortality rate in control palms.

Analysis of EMA residues (ppb) showed a good correlation between doses applied and residues present, with a clear increase of the quantity of active ingredient, untill 90 days after injection. At 180 days after treatment, the variability increased between palms and also between leaves of the same palm. Finally, a strong decline was observed in the EMA residual concentration 360 days after treatment, but this did not prevent a good efficiency against RPW larvae (Figure 8).

Concerning the phytotoxicity study, we dissected completely the four palms treated with 100 ml of EMA looking for signs of phytotoxicity or rot. We found in all the holes a clear phytotoxic effect very localized. In the final end of each hole, the parenchymal tissue and part of the vascular tissue were destroyed forming a necrosis of about 14 x 4 cm around the wound, probably caused by the accompanying solvent of the injected solution (Figure 9). We did not observe rot or development of fungi, neither leaf phytotoxicity.

It can be concluded from this study that there is high interest in the proposed treatment, especially in urban environment where the palms to protect are generally tall.

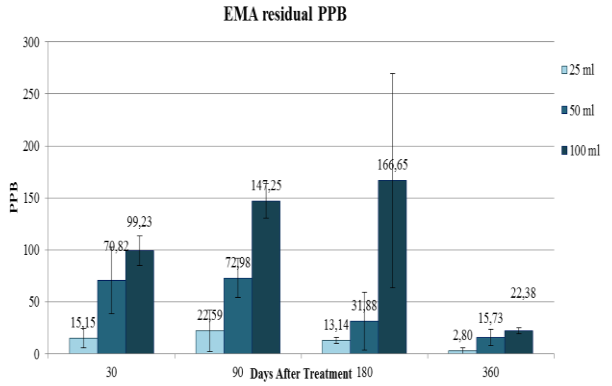

Figure 8. Residual in PPM of EMA in the leaves of the palms injected with 25ml, 50ml and 100ml

One treatment per year, very simple to apply and at a very low cost in the countries where similar EMA formulations are available, constitutes a considerable advantage compared with usual preventive treatments that are delicate and costly to apply in such environment. When this technique was applied on 3000 palms in a heavily infested area in Southern France, less than 1.4% of the injected palms were infested one year after treatment. (CMSP, 2018).

Nevertheless, damaged tissue because of injection will never be regenerated or recovered contrary to what occurs with trees. Consequently, this technique cannot be used indefinitely; its use should be limited to RPW programmes aimed to reduce quickly the pest population. Its use in plantations for date production must also be excluded because of the long persistence of EMA that generates a risk of chemical residue in the fruits, similar to what has been observed with other injected insecticides

Figure 9. Area of the injection with necrosis at the bottom of the hole

الملخص

غومز، سوزي وشي لفيري. 2019. تقنية حقن بسيطة ومنخفضة التكلفة تؤمن حماية فعالة للنخيل إزاء سوسة النخيل الحمراء خلال سنةٍ كاملة. مجلة وقاية النبات العربية، 37(2): 124-129.

يمكن أن تتحمل الميزة الأهم من المعالجات حقن وقائية ضد منر ارمرمل لمكافحة سوسة النخيل الحمراء التي تؤمن حماية فترة طويلة، وتكون التحولات فأفضل ما المعالجات جاهزة لسوسة، مما يسمح للرأس التفريع الأجل المساس بسوسة النخيل الحمراء وكغيرها من المرامل لمكافحة سوسة النخيل والاضرار على الآلية وتشارها وسعة المات من ضروري مارسة المعالجات الوقائية أنتم التقرح تقويات سمية تتيح وقاية كافية ومحيث تكون عائدة وآمنة تزيد فوائد وتقوية سمية جديدة للعمل ضد المحن مرة ضد من الميلي مكتين مزوت تركيز 3.5% أظهرت تطبيقاته تحت ظروف تجريبية مقبولة وغير مستقرة يقارب 100% أشجار النخيل بالقرب أوهان 8 م، مع بقاء فعالية حتى 360 يوم على طول القنوات، مقارنة بـ 11% من سوسة النخيل الحمراء المعاملة.

كلمات مفتاحية: المكافحة، حقن، ميكتين مزوت، سوسة النخيل الحمراء

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Early detection and preventive control of *Rhynchophorus ferrugineus* (Coleoptera Curculionidae): a quarantine pest in Brazil

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Abstract

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Red palm weevil (RPW) *Rhynchophorus ferrugineus* was described as pest from tropical Asia, Mediterranean Europe, North Africa and America (California USA, 2009 and Curacao and Aruba, 2011). There is a risk for RPW invasion in South and Central America, where the weevil could infest economic palms as coconut and Guinean oil palm. The possible invasion represents a severe risk to Brazilian agriculture, and now RPW is an A1 quarantine pest with pending alert. Having available a preventive strategy of monitoring and control before the pest enters the Country would mitigate the threat for the agriculture. Because of this we are developing in Brazil a semiochemical and biological control based strategies for RPW early detection and control. We set tests with Ferrugineol in olfactometer and lured traps in field to evaluate that semiochemical use to evaluate luring of the South American palm weevil (SAPW) Rhynchoporus palmarum as a model pest. Moreover, biological control agents such as entomopathogenic fungi and nematodes are now available for virulence bioassays in Brazil. Field tests will be conducted with a combination of semiochemical and biological agents to determine the level of control with R. palmarum. Subsequently, tests with RPW outside Brazil will be carried out. We expect to find promising combination of mass trapping and biocontrol agent to propose an effective action for the RPW management and the contemporary evaluation of its control efficacy. The study will suggest a new component to develop sustainable control strategies by the joining of intercontinental experiences and approaches**.**

Keywords: Palmaceae, pest alert, insect attack, microbial control, ethological control, America.

Introduction

Red palm weevil, *Rhynchophorus ferrugineus* (Olivier, 1970) (Coleoptera: Curculionidae), hereafter RPW, is endemic in large areas of Asia, but has invaded the Middle East and Europe in the 1980´s, and more recently North America and the Caribbean. The adult beetles are relatively large, ranging from two to four centimeters long, and usually exhibit a rusty red color. However, many color variants exist, which often lead to mis-identifications (Rugman-Jones *et al.* 2013). The larvae excavate galleries up to a meter long and propagate microorganisms (Scrascia, *et al.*, 2016) in the stipe of a palm trees, thereby weakening and eventually killing the host plant. As a result, the weevil is considered a major pest in palm plantations in the world, including the coconut palm, date palm and oil palm (Rochat *el al.,* 2017).

Since 1972 RPW was detected and initiated dispersion in tropical Asia (Indonesia). Between 1980 to 1994 its range expanded to India, the Persian Gulf, and Israel until arriving in North Africa and Mediterranean Europe (Italy, Portugal and Spain) (Rochat *el al.,* 2017). In 2009 RPW was detected in California and in December 2008 in the Caribbean island of Curacao (Roda *et al.*, 2011) and in 2009 in the Caribbean island of Aruba near the Venezuelan coast (Löhr, 2015).

The arrival of this pest to Curaçao is suspected to be due to the importation of mature date palms from Egypt for landscaping in hotel and residential developments (Roda *et al.*, 2011). Shipments of palms from Curacao to Aruba, and the lack of local phytosanitary policies and regulations, have resulted in the most recent establishment of RPW on Aruba. Fiaboe and Roda, (2012) presented prediction maps, based on the adaptability characteristics of the pest, with pest establishment likely in all tropical and subtropical environments of South and Central America and Central Africa.

The first sign of infestation by the pest is yellowing and wilting of palm leaves. The crown wilts first, and lower leaves will follow, due to damage to vascular tissue. Major symptoms such as crown loss or leaf wilt are usually only visible long after the palm has become infested. By the time these external symptoms are observed, the damage is usually sufficient to kill the tree, and the infestation may have been present for six months or longer. In high-density infestations, sounds of the larvae burrowing and chewing can be heard by placing one's ear to the trunk of the palm. Recent research has been conducted using electronic listening devices or dogs trained to recognize the scent of weevils or palm decay to detect infestations at low densities earlier in the process (Rochat *el al.*, 2017).

The prevention of entry of high risk organisms to potentially vulnerable countries is necessary. Such prevention can be achieved through offshore mitigation

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strategies ranging from diagnosis of the presence/absence of a pest threat in adjacent countries and/or territories to eradication. The principal risk at present, is the invasion of South America by RPW, in particular for the main producer countries of commercial palm species like Brazil and Colombia. Brazil has 280,000 hectares cultivated with coconut and 210,000 hectares with oil palms (ABRAPALMA, 2017), while Colombia has 30,000 hectares cultivated with coconut and 470,000 hectares with oil palms (Dane, 2015.; Abrapalma, 2017) which would be endangered by the eventual invasion of *R. ferrugineus.*

In America, another palm weevil exist, with similar behavior and biology, and can be a model for RPW management, called South American palm weevil SPW, *Rhynchophorus palmarum* (Coleoptera: Curculionidae). This weevil is common in virgin forests and in agroecosystems infesting all commercially important palm species mainly of *Cocos nucifera* L. (Arecales: Arecaceae), *Elaeis guineensis* Jaqc. (Arecales: Arecaceae) (Sánchez and Cerda, 1993), in addition to ornamental palm species. The larvae of *R. palmarum* feed exclusively on live vegetative tissue. Studies on the population dynamics of this species in Brazil showed that the maximum adult population peaks during the dry season (Schuiling and Van Dinther, 1981). Bain and Fedon (1951) determined that *R. palmarum* is the most important vector of the phytonematode *Bursaphelenchus cocophilus* (Cobb) (Aphlenchida: Parasitaphelenchidae) which is the causal agent red ring disease of coconut and oil palm disease. The nematode is an obligate parasite distributed in all tissues of the plant. Red-ring disease has reached epiphytotic levels in the past (Griffith, 1968). The external symptoms on infested palms are a progressive yellowing of the foliar area, destruction of the emerging leaf and flowers necrosis. Leaves start to dry in ascending order in the crown; the apical leaf bends and eventually drops. However, these external symptoms are not sufficient for clear diagnosis. Internally, the galleries and damage to leaf-stems produced by the larvae are easily detected in heavily infested plants. Large economic impact of SPW in South and Central America has been reported in Brazil, Colombia, Venezuela and Costa Rica. The larvae of SPW feed on the tender tissue in the crown of the palm, often destroying the apical growth area and eventually causing death of the palm. Economic damage depends on the palm species and on the number of infesting larvae (Dalbon *et al.,* 2018).

Esser and Meredith (1987) estimated that several million USD are lost annually due to the association of red-ring disease and SPW. They estimated that 800 ha of coconut plantations were abandoned due to this disease in Grenada, with 22% of the coconut palms were infested with red-ring disease. A similar situation seems to be common in other countries in America. More recently in Colombia, in the years 2014-2016, the damage of SPW in the pacific coast affected 8,000 hectares of coconut palms and 470,000 ha of oil palm. In Brazil *R. palmarum* affected coconut and oil palms an area of at least 250,000 hectares.

Control strategies have to take into account that SPW is a pest in its own right and a vector of *B. cocophilus*. The control of red-ring disease is currently conducted by controlling the insect vector but there is no efficient control method of the nematode. Chemical control of the insect, although often attempted, is not successful (Hagley, 1963). Cultural control consisting in the eradication and burning of affected trees reduce infestation. Chemical killing and drying of infected plants also reduce infestation (Griffith, 1987), as larvae need living plant tissue in order to survive. The most widely used control methods are based on the capture of adults with traps baited with rotting plant materials, such as palm tissue, pineapple and sugar cane. Recent traps, use synthetic pheromone based to capture the insects. Moura *et al.* (1989) and Rochat *et al.* (1991a) showed that males produce an aggregation pheromone while feeding, attracting males and females equally. Rochat *et al.* (1991b) identified the pheromone as 2(E)-6-methyl-2-hepten-4-ol, naming it rhynchophorol.

SPW was added in 2005 to the EPPO A1 action list, and endangered EPPO member countries are thus requested to regulate it as a quarantine pest. *Rhynchophorus palmarum* presents a significant phytosanitary risk to date palms in Central America, North Africa, and to ornamental palms planted throughout the Mediterranean basin. At present, an integrated pest management (IPM) system for SPW in South America does not exist. New tools, including biological control and further ecological control methods are under development at Universidade Federal of Alagoas in Brazil and Embrapa Tabuleiros Costeiros.

Potential strategies of early detection and control of red palm weevil in Brazil

The potential control tools for R. ferrugineus before its arrival in South America must lie on a preventive and protective approach (Porcelli and Cornara, 2013 and Porcelli *et al.*, 2012), given the previous failure experienced in purely mass-trapping based control.

In the specific case of *R. ferrugineus*, the rapid detection and availability of an array of control tools would avoid great economic losses for the permanent crops of coconut and oil palm. To develop biological and ethological control strategies for the control of palm weevils (*Rhynchophorus palmarum* and *R. ferrugineus*) is necessary to evaluate native and exotic biological agents and semiochemicals, to determine control efficacy, initially in SPW like pest control, to determine the more effective biocontrol for the future containment of RPW in Brazil and South America (Dalbon *et al.*, 2018).

Exploitable foreground

Some examples of biological agents for evaluation, selection and use in IPM for *R. palmarum* and potentially *R. ferrugineus*, in case of invasion in South America, will be mentioned in this paper.

Microbial Agents: Pathogens like fungi (*Beauveria* spp., *Metarrhizium* spp.) and nematodes (*Steinernema* spp., *Heterorhabditis* spp.,) have been applied to suppress pest populations of SAPW and RPW. A wide range of microorganisms suppress pests by producing toxins, causing disease, preventing establishment of other microorganisms or possibly by other mechanisms. Such microorganisms include bacterias, viruses, fungi and nematodes.

Entomopathogenic fungi, have been applied in Brazil since the 1990s. *Beauveria bassiana* strains have been isolated from dead weevils (Santana and Lima, 1992). Since then, EMBRAPA has conducted laboratory and field bioassays in order to develop the pathogenic *B. bassiana* strain CPATC 032 as an effective biological control of *R. palmarum*. The inoculation of adults in pheromone traps (capture – release) can be used to disseminate fungal conidia to other individuals due to the aggregation behavior. Additionally, fungal suspentions can be sprayed on plants (Ferreira and Lima, 1996). Inoculation of fungal conidia of CPATC 032 in combinations with pheromone traps have resulted in reduction of insect population level up to 72.2% (Ferreira and LIma, 1996).

Entomopathogenic nematodes (Rhabditida: Steinenrnematidae and Heterorhabditidae) have been described as an additional biological agent for control of adults of SAPW. The main research had started in 2014 through cooperation between Embrapa Tabuleiros Costeiros and Federal University of Alagoas. Actually in Embrapa in alliance with Colombian Corporation of Agricultural Research Center (AGROSAVIA) created a complete entomopathogenic nematodes bank with species and native strains like *Heterorhabditis amazonensis* JPM4*.; Steinernema carpocapsae* Santa Rosa strain*.; Heterorhabditis* sp. P5*.; Steinernema feltiae; Steinernema brasiliense; Heterorhabditis amazonensis* RS03. *Heterorhabditis amazonensis RS05., Heterorhabditis bacteriophora, Heterorhabditis amazonensis* MSC01. (Acevedo *et al.*; 2018). For RPW, *Heterorhabditis bacteriophora* and *Steinernema carpocapsae* applied in field conditions with chitosan formulation, cause over 80% mortality. Laboratory tests in Brazil indicated that nematode-induced mortality was significantly greater than that produced by the following native nematodes: *S. carpocapsae* Santa Rosa strain, *H. amazonensis* strain JPM4, *S. brasiliense*, *Heterorhabditis* sp P5, with mortalities in larvaes and adults between 80 to 100%. The preliminary results suggested that the use of selected EPN species in field experiments are needed to evaluate their potential under environmental conditions for the control of SAPW and EPN and could use in RPW trials as a potential biological control agent (Acevedo *et al.*, 2018).

Tachinid parasitoids

The natural occurrence of the tachinid parasitoids *Billaea rhynchophorae* and *Billaea menezesi* on larvae of the palm weevil *Rhynchophorus palmarum* (L.) has been documented in plantations of piassava palm (*Attalea funifera* Mart.) and African oil palm (*Elaeis guineensis* Jacquin), in Ilheus, southeastern Bahia, Brazil (Moura *et al.*, 1993, 2006). The average parasitism ranged from 40% up to 72%. The bio-ecology of these parasitoids is currently subject of research by a consortium led by AGROSAVIA with contributions of CEPLAC and EMBRAPA with the aim to introduce the parasitoids to Colombia. The potential of these parasitoids has been completely overlooked in attempts to control *R. ferrugineus* in the Mediterranean and the Gulf region.

An artificial method of massive production of this parasitoid is still unavailable. The development of a method of mass production for an inundative liberation would be an additional management practice for *R. palmarum* and *R. ferrugineus* IPM. Mass rearing of tachinid parasitoids on artificial diet has been developed for other tachinid species (Dindo *et al.*, 2006; 2007) and an effort will be made to adapt this technology to *Billaea* spp.

Pest behavior-modifying chemicals

Semiochemicals are important tools for pest management, either for luring pests to traps, or for disrupting mate or host location. Pheromone-based trapping systems have been used as an efficient method in RPW IPM. Early detection and monitoring help to plan further actions, whereas mass trapping reduces population and infestation levels. Hallett *et al.* (1999) reported that males of RPW were found to produce the aggregation pheromone 4-methyl-5-nonanol (ferrugineol), which attracts both males and females. The use of pheromone-based trapping and an effective management of RPW have been widely demonstrated in the Middle East (Hallett *et al.*, 1999; Soroker *et al.*, 2005; Faleiro *et al.*, 2011). The best semiochemical-based trapping system for RPW in Mediterranean basin is composed of three main components: trap, ferrugineol (the aggregation pheromone) and natural compounds emitted by the host plant (kairomone).

The synthetic kairomone (ethyl acetate/ethanol) was reported to improve the attractant level of ferrugineol. The synthetic blend was as effective as the natural kairomones as co-attractants (plant material + molasses) (Vacas *et al.*, 2017). Though *R. ferrugineus* and *R. palmarum* are closely related, they do not share the same host plant range. The analysis of volatiles from hosts and non-host plants (green leaves, male inflorescence, healthy meristem and decaying tissues) may allow the identification of new kairomones or repellents and masking odours.

The biological control by using entomopathogenic microorganisms is another important technique to be included in any IPM program. The fungi *Beauveria bassiana* and *Metharizium anisopliae* causing high *R. ferrugineus* mortality rates, ranging from 60 to 87%, have been described (Gindin *et al*., 2006.; Dembilio *et al.*, 2010; Lo Verde *et al.*, 2015). Semiochemical-based control methods including mass trapping and attract and infect procedures using entomopathogenic fungi to control RPW have also been reported. Laboratory and field trials have shown that these strains have enormous potential for controlling this palm pest.

Perspectives for integrated pest management for all strategies of control against *R. palmarum* and R. *ferrugineus* in the field in Brazil

The major components of the IPM strategy for *R. ferrugineus* and *R. palmarum* are surveillance, trapping the weevil using pheromones lures, detecting infestation by examination of palms, implementing quarantine measures, training and education (Abraham *et al.*, 1998). In Saudi Arabia, Vidyasagar *et al.* (2000) successfully developed an IPM programme which, in addition to mass pheromone trapping, included a survey of all cultivated gardens and systematic checking of all palms for infestation. A more detailed review of control strategies and IPM for the weevil were also published (Ramachandran, 1998; Murphy and Brisco, 1999.; Faleiro *et al.,* 2011).

The entry of RPW in Brazil without a preventive strategy of monitoring, control and integrated management would be a critical threat for agriculture. In order to develop local early detection and control of RPW in Brazil, we have developed a semiochemical-based and biological control strategy. We set Ferrugineol-lured traps to try attraction tests targeting the South American Palm Weevil (SAPW) *Rhynchoporus palmarum* (Coleoptera Curculionidae) as a model pest. Moreover, kairomones from *C. nucifera* and *E. guineensis*, Ferrugineol in combination with biological control agents in further studies of chemical ecology will contribute to RPW control. Field tests will be conducted by a combination of semiochemical and biological agents to determine the level of control obtained with *R. palmarum.* Subsequently, tests with RPM outside Brazil will be carried out. As a result, we expect to evaluate ferrugineol and other effective volatile compounds for monitoring *R. ferrugineus* after the occurrence of the pest (early detection) in Brazil and contribute with others strategies in IPM of this pest. We expect to join efforts with different institutions in Brazil, South America and International Research Centers and Universities to contribute towards improvement of RPW management.

الملخص

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Studies on service free semiochemical mediated technologies to control red palm weevil *Rhynchophorus ferrugineus* Olivier based on trials in Saudi Arabia and India

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Abstract

Faleiro, J.R., A.-M. Al-Shawaf, H.A.F. El-Shafie and S. Pai Raikar. 2019. Studies on service free semiochemical mediated technologies to control red palm weevil *Rhynchophorus ferrugineus* Olivier based on trials in Saudi Arabia and India. Arab Journal of Plant Protection, 37(2): 136-142.

The red palm weevil (RPW) *Rhynchophorus ferrugineus* Olivier (Coleoptera: Curculionidae) is key invasive pest causing wide spread damage to date palm *Phoenix dactylifera* L. in the middle east and north Africa where it is designated as a category-1 pest by the Food and Agriculture Organization of the UN. Food baited pheromone (ferrugineol) traps have been widely used to both monitor and mass trap adult RPW in palm based agro-ecosystems all over the world since early 1990s. However, due to inherent problems associated with the periodic replacement of the food bait and water (trap servicing) in the traditional pheromone trap, pheromone trapping in area wide IPM programmes to control the pest have become costly and unsustainable. This article presents an overview of the field studies were carried out in Saudi Arabia and India to evaluate service-less trapping techniques of RPW using i) trap free "Attract and Kill" technology and ii) dry trap designed on the principle of electromagnetic communication and olfaction in insects. While "Attract and Kill" studies were carried out in three locations in the Kingdom of Saudi Arabia and one location in India, the dry trap was tested only in Saudi Arabia. Multiple field studies to evaluate "Attract and Kill" tools against RPW showed that large numbers of the adult weevils could be eliminated without the additional effort involved in the periodic servicing associated with the traditional food baited pheromone traps. Furthermore, comparative efficiency of the service-less dry pheromone trap against the traditional food baited traps, revealed that weevil captures in both the dry trap and the food baited traps were statistically similar. The above semiochemical mediated techniques offer sustainable trapping solutions for RPW management, and could be deployed especially in areas where the trap density has to be increased due to high weevil activity.
Keywords: *Rhynchophorus ferrugineus,* semiochemicals, attract and kill, dry trap, repellents.

Introduction

The red palm weevil (RPW), *Rhynchophorus ferrugineus* Olivier (Coleoptera: Curculionidae), is an internal tissue borer attacking palm trees in diverse agro-ecosystems worldwide (Abraham *et al.,* 1998; Milosavljević *et al.,* 2019). During the last three decades, its host range has extended to 40 palm species from only four palm species it was reported to attack during the 1960s. This ten-fold leap in the host range and also increasing geographical expanse of RPW has been mainly after it gained foot hold on date palm *Phoenix dactylifera* L. in the Middle-East during the mid-1980s, where it entered and spread through infested planting material (Al-Dosary *et al.,* 2016; Giblin-Davis *et al.,* 2013). Palms transported within national and across international boundaries for farming and ornamental gardening is the main cause for the spread of this hidden pest which moves through infested planting material (Faleiro, 2006; Milosavljević *et al*., 2019). Inadequate phytosanitary measures and weak enforcement of quarantine regulations at the national, regional and international levels, coupled with constraints in early detection of infested palms due to lack of efficient and easy to use RPW detection devices, along with the inability of known biological control agents like entomopathogenic nematodes and fungi (EPNs/EPFs) to attain and sustain desired control levels of the pest in the field makes RPW control extremely difficult and challenging (Dembilio and Jacas, 2012; Faleiro, 2006; FAO, 2017).

At the farm level, RPW control mainly revolves around pheromone (ferrugineol) trapping, visual detection of infested palms, preventive and curative chemical treatments, and eradication (removal) of severely infested palms. Food-baited RPW pheromone traps are used both for monitoring and also mass trapping the pest (Faleiro, 2006). However, regular renewal of the food bait and water in the traditional RPW pheromone that are commonly used trap makes trapping costly and unsustainable in the long run.

Background

The oldest form of communication among living organisms in the biosphere is through chemical cues. These cues, generally termed as behaviour modifying compounds (BMS) or semiochemicals, have been used for insect pest management. Insect sex pheromones are widely used for the management Lepidopteran insect pests, while aggregation pheromones are commonly used to manage Coleopteran pests (Wyatt, 2003). Due to their natural origin, low persistency in the environment, and species specificity semiochemicals are considered safe and environmentally friendly molecules that are harmless on non-target organisms (Horowitz *et al*., 2009). Despite general progress in chemical

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ecology and potential of semiochemicals, their commercial exploitation in date plantations has been slow. Effective attractants are known for only a few date pests and even for those, their use is usually limited to monitoring (Soroker *et al.,* 2015).

Prior to the synthesis of the RPW aggregation pheromone (ferrugineol) in 1993, trapping of adult weevils in coconut was carried out using food baits, fermenting palm wood, split coconut logs smeared with fresh toddy (Abraham and Kurian, 1975). With the characterization and synthesis of the male produced aggregation pheromone by Hallett *et al*., 1993, food baited bucket pheromone traps have been widely used in both, RPW monitoring and mass trapping programs, where weevil captures are female dominant (Faleiro, 2006). Insect-produced chemicals generate synergy for attraction with host plants, especially in the order Coleoptera (Borden, 1985) and therefore, the RPW pheromone (ferrugineol: 4-methyl-5-nonanol) when used in association with a food bait (dates, sugarcane, banana etc.) acts in synergy to enhance weevil captures, as compared to when the pheromone and food bait are used separately (Hallett *et al*., 1999; Oehlschlager, 2016). In this respect, the chemical co-attractant (ethyl acetate) when used in RPW pheromone traps is known to increase weevil captures (Oehlschlager, 2016). Ferrugineol in association with 10% of its ketone derivative (ferrugineone) is also known to enhance captures (Abozuhairah *et al.,* 1996). Co-attractants based on fermenting compounds, ethyl acetate and ethanol, could improve the attractant level of ferrugineol and potentially replace non-standardised natural kairomones in RPW trapping systems (Vacas *et al.,* 2016).

Although olfactometer assays have shown that RPW pheromone trapping accounts less than 40 % of the population (El-Shafie and Faleiro, 2017), trap captured female weevils are known to be young, gravid and fertile which helps to curtail the build-up of the pest in the field (Faleiro *et al*., 2003). However, foods baited pheromone traps have to be regularly serviced, when the food bait and water has to be renewed, which is costly and not sustainable in the long run especially in an area-wide operation involving several hundred traps. Besides trap servicing, recording of weevil captures is essential in decision making and validation of RPW control programs. In this context, it is essential to have smart trapping devices for the efficient management of RPW (Aldhryhim and Al-Ayedh, 2015). RPW semiochemical mediated technologies of the future therefore need to focus on the development of technologies that not only eliminate the need of trap servicing and develop lures that stand-alone but also which could be deployed in a smart trapping device for the overall improvement in the trapping efficiency, data collection and transmission (El-Shafie and Faleiro, 2017).

This paper looks at three service-free RPW semiochemical mediated technologies *viz.* i) attract and kill, ii) dry pheromone traps, and iii) RPW repellents tested in Saudi Arabia and India.

Overview of service-free RPW semiochemical mediated technologies

Attract and Kill - In Attract and Kill (A&K), the insect pest attracted by a semiochemical (pheromone) lure is not "entrapped" at the source of the attractant as in mass trapping, but instead the insect is subjected to a killing agent, which eliminates affected individuals from the population after a short period (El-Sayed *et al.,* 2009). A&K technique is used to control insect pests in a wide range of crops. Brown marmorated stink bug *Halyomorpha halys*, an invasive, polyphagous insect that causes serious economic injury in particular to specialty crops like apple in the United States is an important example where this technique is used**.** Several case studies in which A&K has been used with the aim of long-term pest management include pink bollworm, Egyptian cotton leaf worm, codling moth, apple maggot, biting flies, bark beetles, and the eradication of invasive tephritid fruit flies and boll weevils (Camelo *et al.,* 2007; El-Sayed *et al.,* 2009; Hossain *et al.,* 2005; Marfa-Neto *et al.,* 2014; Mazomenos *et al.,* 2002; Morrison *et al.,* 2015). The technique is used in integration with other IPM methods.

In the case of RPW, the potential of using A&K as a component of the RPW-IPM strategy was first studied with a commercial formulation (Hook-RPW™: 15% ferrugineol and 5% cypermethrin) by El-Shafie *et al.* (2011). Subsequently, extensive field trials were carried out in Saudi Arabia and India with A&K systems (Hook-RPW™; Smart Ferrolure™).

A&K formulation against RPW developed by ISCA Technologies, USA (Hook-RPW™) was extensively field tested in date palm in Saudi Arabia; while A&K systems against RPW by Chem Tica International, Costa Rica (Smart Ferrolure™) were tested for palm protection against RPW in large field trials in date and oil palm plantations in Saudi Arabia and India, respectively (Faleiro *et al.,* 2016a; Faleiro *et al.,* 2016b).

Dry traps - Stand-alone RPW pheromone traps without the food bait and water have been advocated in the past (El-Shafie and Faleiro, 2017). This will substantially cut the cost of sustaining and replenishing the food bait and water associated with the traditional RPW food baited pheromone traps commonly used in RPW-IPM programs. The Electrap™ is an advancement in this direction and offers a sustainable service-less trapping option for RPW especially in areas where the trap density has to be increased due to high weevil activity. The Electrap™ functions on the principle that insects communicate by radiations emitted from oscillating molecules (Al-Saroj *et al.,* 2017).

RPW repellents - The possibility of identifying and deploying insect repellents with pheromones in an area-wide programme involving a push-pull strategy could open a new semiochemical mediated strategy for the sustainable management of RPW. α-pinene, singly or in combination with methyl salicylate or menthone has been identified as a potential RPW repellent (Guarino *et al.,* 2013). Further studies are necessary to identify RPW repellents and quantify the extent of palm protection RPW repellents could provide.

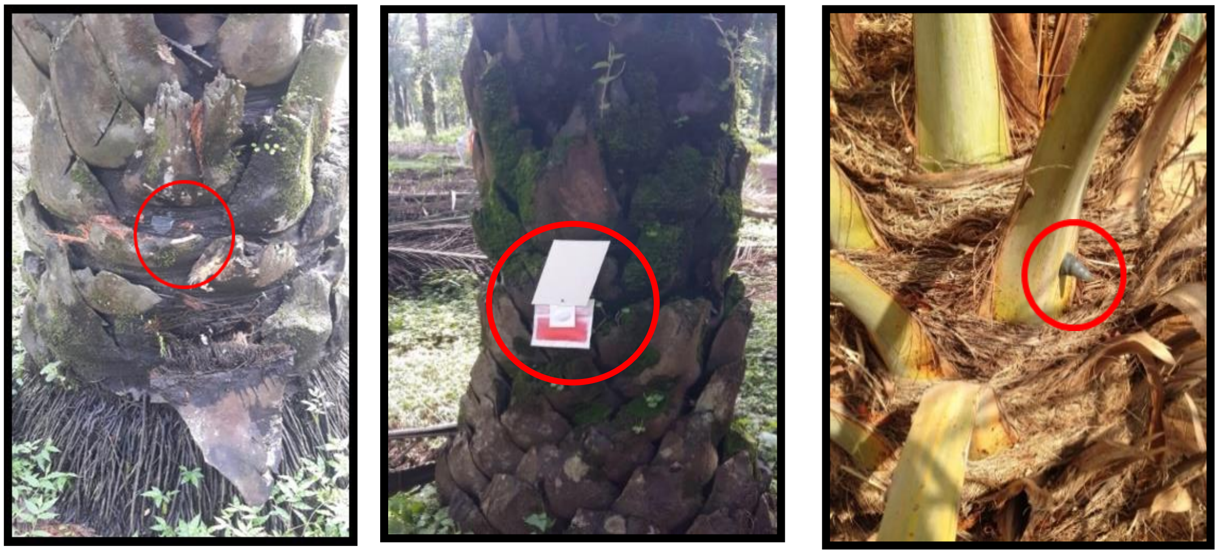

Figure 1. RPW attract and kill systems; Smart Ferrolure paste (left) with a dead weevil and Card device (middle), Hook RPW Dollop (right)

Field trials on service-free RPW semiochemical mediated technologies in Saudi Arabia and India

Attract and Kill - In a field trial in Al-Qassim, Saudi Arabia, Hook-RPW™ (ISCA Technologies, California, USA) was applied as two-4g dollops of Hook-RPW™ (30% ferrugineol + 5% cypermethrin) to the base of the palm with a caulking gun @ 400 dollops per ha), (Faleiro, et al., 2016a). Attractiveness and killing of RPW adults were recorded throughout the experimental period of 23 weeks, in 10% of the points set in four-window bucket containers closed with a lid. The traditional food-baited RPW pheromone traps were set at 1trap/ha in A&K treated plot (10ha) and also in a control plot (8ha) without A&K.

A total of 209 weevils were attracted and killed by just 10% of the points in the A&K treated plot with Hook-RPW™. Also, the mean trap captures in RPW pheromone traps set in the experimental plot was significantly lower as compared to captures in the control plots with no A&K treatment, clearly indicating that the A&K system removed a large number of weevils in the A&K treated plot (Faleiro, et al., 2016a).

With respect to Smart Ferrolure™, two A& K systems of 'Smart Ferrolure™' from Chem Tica International, Costa Rica *viz.* i) a card A&K device and ii) paste formulation, were tested in RPW infested date plantations of Al-Ahsa, Saudi Arabia on 01 September to 23 November, 2015 and 06 September to 02 December, 2015, respectively (Faleiro et al., 2016b). The card A&K device [card: wax with 5% cypermethrin + ferrolure 700mg+ethyl acetate (weevil magnet ™)] was installed in the field (2ha) at a density of 30 points/ha (Faleiro *et al.*, 2016b). The paste formulation [15% ferrugineol + 5% cypermethrin] was deployed in a 3ha plantation as a 3g dollop @ 250points/ha.

The dead weevils in the points set in containers in the trial sites revealed that both the card device and paste formulation of Smart Ferrolure™ attracted and killed RPW adults. However, the paste formulation killed significantly more weevils (16 weevils in only 10% A&K points) as evidenced from the dead weevils in the containers as compared to the card system (only 9 weevils in 50% of the points). While results with the paste were encouraging, the card exhibited significantly low killing capacity in about 45 days after exposure in the field, probably due to accumulation of dust on the card that prevented contact of attracted weevils to the insecticide.

In India, both the above card device and paste formulation of 'Smart Ferrolure™', by Chem Tica International, Costa Rica were tested in two field trials from 01 September, 2015 to 09 April, 2016 in the same RPW infested oil palm plantation belonging to Godrej Agrovet Limited, Valpoi, Goa, India. Each A&K system (paste and card) was tested in 8 ha (Faleiro et al., 2016b). In these trials, 15 % of the points were set in open containers to record weevil that get attracted and killed. In all the trial sites in Saudi Arabia and India a trap density of 1trap/ha was maintained and other routine RPW-IPM practices carried out.

From the trial in the oil palm plantation in India with Smart Ferrolure™ (Figure 2), it is evident that the paste formulation of Smart Ferrolure™ was superior as compared to the card system. RPW population reduced by 89% at the end on trial-II using the paste formulation of Smart Ferrolure™ as compared to the card system where adult population reduced by only 41% (Faleiro *et al.,* 2016b).

Dry Trap - Weevil captures in two field trials revealed that the treatments (Picusan Trap™, Electrap™ and the traditional bucket trap) were statistically similar (Al-*Saroj et al*., 2017). However, recent report (Kharrat *et al.,* 2018) based on trials carried out against *R. palmarum*, indicated that the attraction may be due to the pheromone/synthetic attractant rather than electro-magnetic radiation, which is contrary to the claim that the functioning of the Electrap™ is based on the concept that insect communication is mediated by radiation. This mechanism of electromagnetic communication and olfaction in insects has been previously reported by several workers (Laithwaite, 1960; Callahan, 1965).

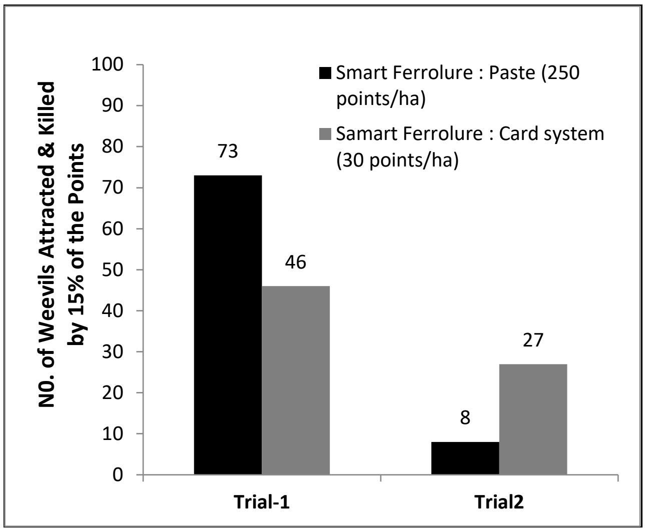

Figure 2. RPW Attracted & Killed by Smart Ferrolure™ tested on Oil Palm [01 September, 2015 to 09 April, 2016]: Goa, India. Trial-I: 01 September-30 November, 2015; Trial-2: 10 January-9 April, 2016 (Source: Faleiro *et al.,* 2016b).

RPW Repellents - A push-pull strategy deployed in combination with a repellent and attractant has been proven useful for the management of several species of bark beetles (Borden *et al.,* 2006) and needs to be tested against RPW.

Replicated field trials were carried out in Al-Ahsa between 2011 and 2012 to screen 45 know insect repellents through trap shut down studies. Four promising repellents identified (GCC patent pending) in these trials were further tested for tree protection in a 10 ha RPW infested date plantation where these repellents were installed at 50 repellents/ha, while RPW pheromone traps set at 1 trap/ha were installed at the periphery of the test plot in a push-pull design. A control plot (10 ha) without the repellent was also maintained and weevil captures in the treated and control plot were compared at the end of the experimental period (April-July 2014). In addition to the above, replicated field trials were also carried out in Al-Ahsa to ascertain the repellent potential of verbenone against RPW through trap-shut down studies (Faleiro, 2016).

Four RPW repellents were identified through trap shut-down studies with over 80% trap shut down (Faleiro, 2012). The repellents are currently being vetted for a GCC patent. Furthermore, upon testing of these repellents in a push pull system, weevil captures in plots with pheromone traps treated with the repellent recorded higher weevil captures indicating that the pest was repelled from the repellent treated plot but weevil captures in traps were statistically similar in plots without the repellent. It may be necessary to increase the repellent density per unit area from the 50 repellents/ha tested to obtain adequate repellency effect. Trials with verbenone against RPW resulted in 75% trap shut down. Further testing of these RPW repellents for palm protection is required (Faleiro, 2016). Testing RPW repellents with the service less Electrap™ or A&K technology in a push-pull system also needs to be evaluated.

Conclusion

RPW adults attracted and killed by both Hook-RPW™ and Smart Ferrolure™ in the above trials clearly indicates that a trap density of 1 trap/ha was not sufficient in trapping the adult weevils in the test plantations. Pheromone trap densities in area-wide RPW-IPM programs range from one to 10 traps per hectare (Faleiro *et al.,* 2011; Oehlschlager 2006; Soroker *et al.,* 2005;). However, increasing the trap density is often not possible due to the periodic servicing (change of food bait and water), necessary to sustain the trapping efficiency. In this context, the 'trap and bait free' A&K option could significantly augment the mass trapping programme of RPW by killing the emerging adult weevil population in the field. A&K technology can successfully eliminate adult RPW population. The technology serves as an excellent tool to manage RPW population where infestations are high, or in plantations that are inaccessible and neglected and could significantly strengthen the on-going pheromone trap based RPW-IPM strategy particularly in plantations where the pheromone trap density has to be increased to effectively mass trap the adult population. The cost involved in the periodic servicing associated with the traditional food-baited pheromone traps is effectively eliminated with this 'bait and trap free' technique of controlling the adult RPW population in the field. However, a minimum of one food baited pheromone trap/ha is required to be maintained in an area-wide RPW control programme to gauge weevil activity in the field. Furthermore, A&K has the potential to do away with the need to take up routine periodic preventive insecticide sprays. The technique has been used in RPW-IPM programs in date palm, the canary palm and coconut in Mauritania, Abkhazia in the Republic of Georgia and Malaysia, respectively.

All safety precautions (wearing of gloves, mask, foot wear, etc.) need to be complied with while applying RPW A&K formulation in the field. In case of allergic reaction or coming in direct contact with the product, further application should be stopped, immediate medical assistance sought and the manufacturer contacted.

The Electrap™ is an efficient service free semiochemical mediated technology against RPW and can be incorporated in RPW-IPM programs. However, known RPW repellents need further testing to be incorporated in an RPW-IPM program involving a push-pull strategy.

الملخص

فاليرو، جوزيه روميو، عبد المنعم الشواف، حمد بن عبد الله الخليفة وسوم باباراجو كريشنا. 2019. دراسة تأثير تقنيات الاتصال ولا تلامس في مكافحة سوسة النخيل الحمراء Rhynchophorus ferrugineus Olivier في المملكة العربية السعودية ولبنان. مجلة وقاية النبات العربية، 37(2): 136-142.

تعد سوسة النخيل الحمراء *Rhynchophorus ferrugineus* Olivier (فصيلة السوسيات Curculionidae رتبة غمديات الأجنحة Coleoptera) آفة غازية رئيسية لأشجار النخيل *Phoenix dactylifera* L. تسبب خسائر فادحة في مناطق الخليج العربي وشمال أفريقيا والشرق الأوسط ودول البحر المتوسط. ... (نص عربي غير مقروء بسبب خلل في ترميز الخط) ...

كلمات مفتاحية: سوسة النخيل الحمراء، مصائد، الجذب، مصيدة، ...

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Microwave heating: a promising and eco-compatible solution to fight the spread of red palm weevil

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Abstract

Massa, R., G. Panariello, M.D. Migliore, D. Pinchera, F. Schettino, R. Griffo, M. Martano, K. Power, P. Maiolino and E. Caprio. 2019. Microwave heating: a promising and eco-compatible solution to fight the spread of red palm weevil. Arab Journal of Plant Protection, 37(2): 143-148.

The red palm weevil is one of the major pests of palms. Until now no effective and economic method has been adopted for the total eradication of this pest and some concerns are raised for chemical methods, mainly in ornamental plants located in urban areas. Among the proposed techniques, a very promising and eco-compatible solution is the palm microwave heating, which could be integrated in a IPM approach. Advantages of microwave disinfestation include speed, efficiency and the absence of toxic, hazardous or polluting residues. Moreover, insects are not likely to develop a resistance to radiation as they often do to chemical insecticides. This work aims to resume our results on the feasibility of microwave applications on infested *Phoenix canariensis* palms. Temperatures that can be lethal to insects applied on the external layers do not affect the internal palm tissues. Moreover, microwaves can influence the ability of reproduction of the survived weevils. Once the physical/thermal parameters of the tissues were determined, a protocol of duration of time and schedule (on-off cycles) was developed for a better control of the temperature profile inside the palm. In this way, the lethal temperature dose for the insects was applied using a ring microwave applicator.

Keywords: non ionizing radiation, pest control, alien invasive pest.

Introduction

The invasive Red Palm Weevil (RPW), *Rhynchophorus ferrugineus* Olivier (Coleoptera, Curculionidae) is one of the most destructive pests in palms in the world. In the Mediterranean Basin it is particularly damaging for *Phoenix canariensis* Hort. ex Chabaud. Different control methods have been applied within an integrated pest management (IPM) strategy (Gliblin-Davis *et al.*, 2013) including synthetic insecticides, insect traps, plant extracts and biological control (Ajlan, 2000; Di Ilio *et al.*, 2018; El-Shafie *et al.*, 2011; EPPO, 2008; Faleiro, 2006; Murphy and Briscoe, 1999; Nassar and Abdullah, 2001; Oehlschlager, 1993; Wattanpongsiri, 1966). Until now no effective and economic method has been adopted for the total eradication of RPW and chemicals techniques are the most used. Due to different commercial products authorized by the national ministries of different countries, different results in the applications of the adopted molecules both in ornamental and date palms have been obtained. For this reason, a considerable interest towards solutions able to control the pest, with a minimum impact on the environment, has risen. The experience gained until now suggests that it is necessary to adopt preventive strategies that have primarily a protective character. If the palms are treated in the early stages of attack they can recover and their stability is not compromised. In this contest microwave heating is a particularly interesting tool. In recent years this technique has attracted great interest in the environmental engineering field. It is based on the transformation of the energy of these non-ionizing radiations, which cover both radiofrequency (RF) and microwaves (MW), into thermal energy when they interact with polar molecules (as water) and ions (Gabriel *et al.*, 1996). Dielectric heating has been investigated for several applications designed for the volumetric heating of materials as rubber, wood, paper, agricultural products, for food processing and disinfestations (wheat, rice, fruit) (Lewandowski, 2001; Vincent *et al.*, 2003; Wang and Tang, 2001; Wang *et al.*, 2003) and it has been approved by the International Plant Protection Convention (IPPC) for the treatment of wood packaging materials, according to ISPM 15 Regulation of Wood Packing Material in International Trade of the FAO (FAO 2014, 2018; Henin *et al.*, 2014). The idea of using MW against RPW is based on the fact that this radiation should be able either to induce a thermal increase in the pest, heating it to a lethal temperature without harming the plant tissues, or to affect the reproduction of survivors as reported in other papers (Hamid, 1968). In this work we present the feasibility of this approach and its application in *Phoenix canariensis* palms. The efficacy of the treatment has been proved in semi-field tests. RPW lethal temperatures can be easily reached in the external layers of the trunk. The surviving RPW (time) can be reduced as MW is able to affect their longevity and induce morphological alterations of the

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ovaries and testes in adult RPWs (both male and female). The measurements of thermal and electromagnetic parameters of the tissues involved (both insect and plant host) allowed to develop a thermal-electromagnetic model that is the base of a software validated both numerically and experimentally. The treatment can be optimized on the basis of the evaluation of the performance of the applicator and the developed tool, that can be easily adopted by not skilled operator. Once parameters (dimension of the palm, ambient temperature, wind conditions, penetration depth) are set, it is then possible to establish the power, modulation and duration of the treatment.

Effectiveness of palm microwave sanitation in laboratory and semi-field tests

The feasibility of microwave treatments of *Phoenix canariensis* to control RPW was reported by Massa *et al*. (2011). A preliminary semi-field test was performed on an infested plant (30 cm diameter) treated with a truncated waveguide connected to a magnetron source (2.45 GHz, 1 kW) for 30 min. During irradiation, thermal images were recorded with an infrared (IR) thermocamera and data showed that only the external region of the palm directly involved in the treatment reached high temperatures (about 70 °C). Larvae and adults present in this section were found dead. These results highlighted a low thermal conductivity and were in agreement with that expected on the basis of laboratory tests on the electromagnetic characterization of both plant tissues (healthy and damaged by the pest) and insects (Massa *et al.*, 2011; 2014). The data showed a microwave penetration depth of the order of a couple of centimeters at 2.45 GHz, due to the high water content in the plant tissues. In particular, by applying Ulaby model to our data (Ulaby and El-Rayes, 1987), the volume fraction of free water resulted higher than that of the bulk vegetation-bound water mixture in the damaged tissues. In the case of insects at 2.45 GHz, the loss factor on the surface of the adult resulted much lower than that of the larva (due to the reduced water content of the insect at this stage compared to that of the larva), and the penetration depth in the chamber was of many centimeters, thus allowing microwaves to reach the larva/adult depending on the stage of metamorphosis.

Microwave exposures carried out in the laboratory under controlled conditions confirmed these results. Larvae or adults were introduced into a short-circuited waveguide fed by a microwave source (2.45 GHz), incident and reflected powers were measured by power meters and temperatures were monitored by an IR thermocamera (Figure 1). With an incident power density of 5W/cm^2, larvae suddenly reached lethal temperature, while adults longevity depended on the time exposure.

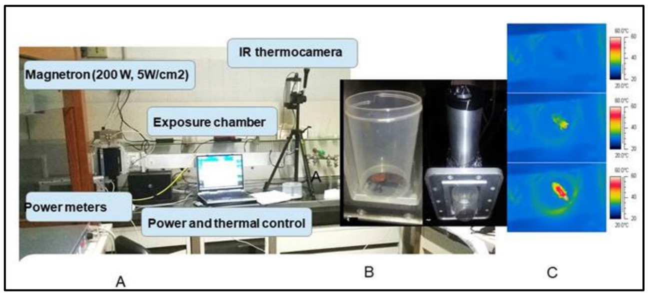

Figure 1. (A) Microwave exposure set up; (B) insect inserted into the waveguide; (C) thermogram acquired during the exposure

Finally, an additional set of tests was performed on bigger *Phoenix canariensis* palms (50 cm diameter) to estimate the efficacy of the treatment and the effect of the induced thermal stress. Eight out of thirteen palms were infested. Four infested palms and two healthy plants were microwave treated with a commercially available ring applicator (Ecopalm ring, Bielle s.r.l.). In Table 1 the exposure time and the number of alive and dead insects found in dissected palms (24 h after treatment) are reported.

As expected, an extremely high mortality was recorded in the case of insects blocked into cocoons. Adults were more affected than larvae (that were probably more inside the plant). The total effectiveness was between 60-90%. Regarding the healthy microwave treated plants, they were observed for one month and compared with healthy and un-treated palms. No effects of thermal stress were qualitatively observed.

Impact of microwaves on RPWs reproductive organs

Among the factors that influence the RPW's invasive potential there are the ability to complete several generations in a year even in the same tree and the high female fecundity. Females are usually attracted by palm volatiles and lay several eggs in dying or damaged parts of palms, although undamaged palms could also be attacked. After few days, eggs hatch into larvae which develop within the trunks of palms, frequently leading to the plant death (Faleiro, 2006; Giblin–Davis *et al.*, 2013; Murphy and Briscoe, 1999; Wattanpongsiri, 1966).

Table 1. Effectiveness of the treatment. Alive or dead insects found after microwave treatment

Infested Palm	Treatment time	Living Adults	Dead Adults	Living Larvae	Dead Larvae	Living Pupae	Dead Pupae	%Dead Adults	%Dead Larvae	%Dead Pupae	%Dead Total
#1	30 min	3	1	0	0	0	6	25	-	100	70
#2	45 min	2	25	3	2	0	6	92	40	100	87
#3	45 min	15	21	0	0	3	6	58	-	67	60
#4	45 min	5	10	0	1	0	1	67	100	100	71

At present, different pest control methods have been adopted. Nevertheless, none has proven completely effective. Currently, a Sterile Insect Technique (SIT) (Dyck *et al.*, 2005) is being developed to reduce fertility of the entire population of a specific pest in a particular area with minimal toxic effects (Llacer *et al.*, 2013). Exposure to ionizing radiation is currently one of the methods for rendering insects reproductively sterile and it was proven effective even in RPW (Al- Ayedh, 2008; El Naggar *et al.*, 2010; Paoli *et al.*, 2014). Recently, microwaves heating has proven to be very useful in the environmental field. In a recent study, the morphologic and histological features of the male and female reproductive system of the RPW irradiated (Figure 1) at three different exposure time (5 s, 15 s, and 30 s) with microwaves (2.45 GHz, 5 W/cm^2) were investigated (Martano *et al.*, 2018). This study reported that the histological lesions in irradiated male and female RPWs were characterized by alterations of various severity levels ranging from degeneration to necrosis of germinal cells (Figure 2). The severity of the lesions increased with increase of irradiation time, showing severe alterations (necrosis) at 30 s, in all female samples and in almost all males (75%). Furthermore, the histological effects of radiation were similar to that observed in RPWs treated with insecticidal agents (El-Bokl *et al.,* 2010), gamma rays (El Naggar *et al.,* 2010; Paoli *et al.*, 2014) and zinc sulfate (Al-Dhafar and Sharaby, 2012). Based on the results obtained, authors suggest that the impact of MWs on ovaries could lead to a progressive reduction of egg production and sterility of eggs, while on testis could induce loss of germinal cell, leading to a total lack of germ cells, with consequent arrest of spermatogenesis. These observations allow us to say that the MW could be an efficient way to reduce RPW population, because they could reduce or stop completely the reproductive ability of this insect.

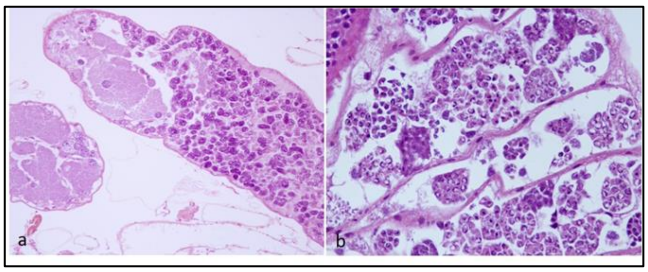

Figure 2. (a) Female RPW. Ovary. Vacuolar degeneration and necrosis of germinal cells were observed in 30 s irradiated samples (c; 20X) (Hematoxylin and Eosin). (b) Male RPW. Testis. In 30 s irradiated samples degenerative changes appeared in the precursors of spermatids and seminal epithelium (40X) (Hematoxylin and Eosin).

Microwave optimization treatment

One of the key problems in the microwave treatments of palms is their optimization, i.e. to estimate the microwave energy that must be radiated in order to reach the lethal temperature for the insect without damaging the palm. To reach this goal we proposed an electro-thermal model allowing the simulation of the thermal and electromagnetic processes involved in microwave heating. The model was validated both numerically and experimentally (Massa *et al.*, 2017) and resulted in an in-house software named ThermPalm.

In this article a brief description of the steps followed to develop such a model is sketched. The interested reader can find more details in earlier reports (Massa *et al.*, 2017), while in this paper we focus the attention on the practical indications obtained from the simulations, with special attention to the ThermPalm program results, that allow to identify the power, time and schedule necessary to obtain the lethal temperature at a certain depth, depending on the assumed palm infestation level.

We assumed a rapid substitution, during irradiation, of the evaporating water by other water drained by the plant (as Ulaby model suggested) and a negligible temperature dependence of thermal and electromagnetic parameters. In addition, we considered a cylindrically symmetric microwave illumination around the trunk of the palm and a longitudinal invariance. Consequently, all physical quantities in both thermal and electromagnetic models only depend on the radial coordinate and time and the analysis can be easily carried out by means of an FDTD (Finite Difference Time Domain) approach.

The thermal parameters of the palm were evaluated on an alive palm by measuring the temperature behavior during both microwave heating and cooling phases (Massa *et al.*, 2017). To this end, a WR340 waveguide, fed by a magnetron source (1 kW incident power), was placed in front of the palm to be heated and two fiber optic probes, connected to the thermometer, were positioned at different depths inside the palm allowing accurate and non-perturbative temperature measurements in two points along the radius of the palm. The measurements of electromagnetic parameters, determined with the truncated coaxial technique (Migliore, 2000; Panariello *et al.,* 2001; Romeo *et al*., 2011) and the mass density, are reported earlier (Massa *et al.*, 2014). On the basis of thermal and electromagnetic parameters, taking into account the boundary conditions, and both natural and forced convection, a simple mono-dimensional electromagnetic-thermal code is able to predict, quite in real time, the thickness of the annular area in "living" palms wherein the RPW lethal dose (temperature and time) is reached without damaging the palm core that is the most relevant area for the life of the palm itself. The code has been employed with the commercial ring microwave applicator EcoPalm (patented by Bi.Elle s.r.l., (Figure 3) but could be used with different applicators. It consists in 12 magnetrons (2.45 GHz, 1kW nominal power) arranged in a ring that can be closed around the palm in order to surround a section of the trunk. The magnetrons can be automatically controlled in order to optimize the treatment and can be turned on and off with a proper temporal cycle in order to increase the temperature inside the palm without reaching a too high temperature on the surface.

The user can set a number of parameters: environmental temperature, diameter of the palm, presence of wind, treatment depth and goal temperature. Other parameters are the power of the microwave applicator and the section of the palm to be treated (i.e. the height of the section of the palm), depending on the applicator. On the basis of these information the output is the duration of an on-off sequence of the magnetrons able to give the target temperature within the treatment depth set.

Figure 3. The EcoPalm ring applicator (patented by Bi.Elle s.r.l.).

As an example, we consider a 40 cm diameter palm, environmental temperature of 20 °C with no wind, 10 cm treatment depth and 55°C as goal temperature. The program identifies an optimal treatment with 7 on-off sequences lasting 7 min each.

In Figure 4, the heat distribution during the treatment is shown. The central figure (black curve) represents the turn on and turn off sequence. The temperature distribution (false colors) in a section of the palm and at different depths are shown in the higher and lower figure, respectively. At the beginning (time t=0) the section of the palm has uniform temperature equal to the environment temperature. Then the magnetrons are turned on at the maximum power for 7 minutes. The increase of the temperature in the palm is clearly visible in the lower figure. Then the magnetrons are turned off. The outer part of the palm starts cooling, while the inner part increases the temperature due to the thermal diffusion process. After 7 minutes, the magnetrons are turned on again, causing a fast increase of the temperature on the outer part of the palm section. This helps the increase of the temperature in the inner part of the palm caused by the diffusion process. This turn-on turn-off process is repeated in order to meet the requirements set in the ThermPalm window.

The simulation clearly shows the physical processes at the basis of the increase of temperature of the palm. The microwave power is directly transferred to the palm tissue in the first 4-7 cm, due to its high water content that strongly limits the penetration depth of microwaves inside the palm. In this area temperature increases very quickly since it is caused by direct microwave energy delivery. Instead, in the inner sections of the palm the thermal increase is due to the low heat conduction that is a much slower process. The on-off optimized sequence balances this two heating processes, allowing to reach the target temperature without dangerous thermal stress of the outer part of the trunk. It is worth noting that heat transfer due to convection on the surface of the palm is a parameter that plays an important role. Indeed, cooling of the surface can modify the temperature distribution inside the palm. In Figure 5, it is shown that the estimated temperature distribution inside the palm at the end of the on-off sequence with and without wind. A shift of the maximum temperature can be observed.

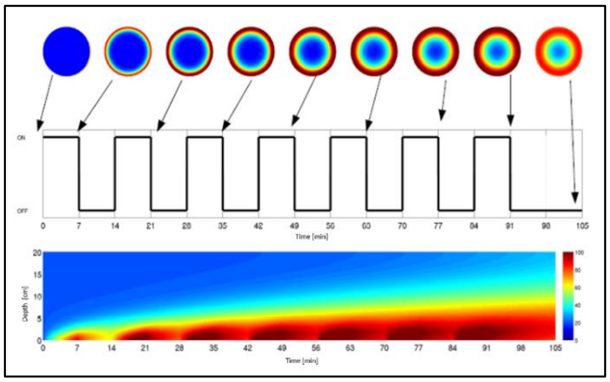

Figure 4. Temperature distribution in false colour in a section of the palm as function of time during the on-off cycles of the microwave applicator; the black curve represents the turn on-turn off sequence of the magnetron; in the lower figure the temperature at different depths of the palm (vertical axis of the figure) as function of time (horizontal axis of the figure) is shown; depth=0 is the surface of the palm, depth= 20 cm is the radius of the palm.

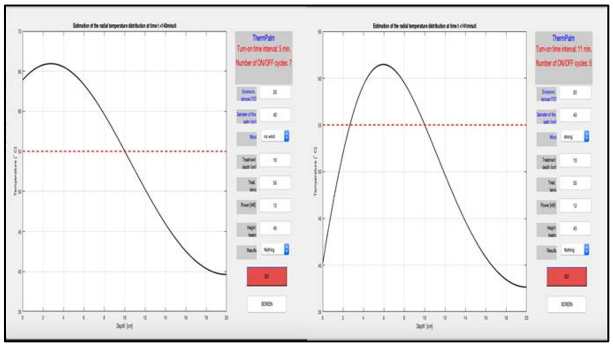

Figure 5. effect of wind on temperature distribution in the palm: left – no wind, right – strong wind.

Conclusions

MW heating of *Phoenix canariensis* palm resulted in an efficient, cheap and eco-compatible method to control RPW without affecting the plant, which could possibly be integrated in an IPM approach. Data showed that, with the adopted conditions, the microwave heating affects only the outer section of the palm, while the core remains quite cool. This is a relevant feature, since it matches two important requirements: the layers involved in the process are the regions where both the early stage and the pupal stage occur (it is worth noting that if the pest reaches the inner tissues, the palm irremediably dies and any treatment is useless); while keeping the core of the palm at lower temperature guarantees that microwaves do not affect the health of the plant. The process can be optimized by means of a suitable heating/cooling cycle, estimated by an in-house software implementing a simple electro-thermal model, validated both numerically and experimentally.

The knowledge and experience gathered in the case of *Phoenix canariensis* could be extended to other palm species attacked by one of the most destructive pests in the world.

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الملخص

ماسا، ر.، ج. بانارييلو، م. د. ميغليوري، د. بينشيرا، ف. شيتينو، ر. جريفو، م. مارتانو، ك. باولو، ب. ليوني و إ. كابريو. 2019. تطبيق الموجات الدقيقة: حلٌّ واعد وملائم بيئياً للحدّ من انتشار سوسة النخيل الحمراء. مجلة وقاية النبات العربية، 37(2): 143-148.

تعدّ سوسة النخيل الحمراء من الآفات الرئيسة لأشجار النخيل. ولغاية تاريخه لم يتمّ اعتماد طريقة ناجعة ومجدية للقضاء على هذه الآفة بصورة كليّة، فضلاً عن ظهور مخاوف بشأن استخدام الطرائق الكيميائية للمكافحة ولاسيّما في حالة نباتات الزينة المزروعة ضمن المناطق الحضرية المدنية. ومن بين التقنيات المقترحة، يعدّ التسخين بالموجات الدقيقة الكهرومغنطيسية لنباتات النخيل حلاً واعداً وصديقاً للبيئة، ويمكن دمجه ضمن برامج المكافحة المتكاملة للآفات. وتشتمل مزايا التخلّص من الآفة باستخدام الموجات الدقيقة على السرعة، الكفاءة، وغياب المتبقيات السامّة والخطرة أو الملوثة؛ فوق ذلك فمن غير المرجّح بروز حشرات مقاومة للإشعاع على غرار ما يلاحظ غالباً تجاه المبيدات الكيميائية. يهدف هذا العمل إلى تتبع نتائج حول الجدوى من معاملة الموجات الدقيقة على أشجار نخيل الزينة *Phoenix canariensis* المصابة. إنّ درجات الحرارة التي يمكن أن تقتل الحشرات والمطبقة على الطبقات الخارجية للنباتات لا تؤثّر على أنسجة الخلايا لشجرة النخيل؛ وعلاوة على ذلك، يمكن للموجات الدقيقة أن تؤثّر على القدرة التكاثرية لحشرات السوس البالغة. عقب الانتهاء من تحديد المؤشرات الفيزيولوجية/الحرارية للأنسجة النباتية تمّ تطوير بروتوكول للمدّة الزمنية وجدولاً زمنياً لدورات التشغيل-الإيقاف للوصول إلى تحكّم أفضل بوضع درجات الحرارة داخل نسيج النخيل. وعلى هذا النحو فقد تمّ تطبيق جرعة الحرارة القاتلة للحشرات باستخدام قضيب الموجات الدقيقة الحلقي.

كلمات مفتاحية: أشعة غير مؤيّنة، أشعة، مكافحة آفة، آفة دخيلة غازية.

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Efficiency of food baits, synthetic attractants and trap type on *Rhynchophorus ferrugineus* (Olivier) trapping in Palm Plantations, Ismailia, Egypt by aggregation pheromone traps

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Abstract

El-Banna, A., M.K. Abbas, A. Hala and T.M. Ibrahim. 2019. Efficiency of food baits, synthetic attractants and trap type on *Rhynchophorus ferrugineus* (Olivier) trapping in palm plantations, Ismailia, Egypt by aggregation pheromone traps. Arab Journal of Plant Protection, 37(2): 149-150.

Number of captured weevils were significantly affected by trap types, where PICUSAN® trap gave the highest captured number during the experimental period, which lasted for 7 weeks. The combined effect of sugarcane honey, pheromone, ethyl acetate and pesticides gave more attractiveness than the other four combinations tested.

Keywords: *Rhynchophorus ferrugineus*, pheromone traps, kairmone.

Introduction

Pheromone trapping of the red palm weevil *Rhynchophorus ferrugineus* (Olivier) is considered an environmentally safe tool in the IPM adopted strategy worldwide in date palm plantations. Field trials were conducted in Kasassin District, Ismailia Governorate, Egypt, to enhance the RPW pheromone-trapping efficiency. The current study was carried out during two successive years from April 22, 2015 until October 10, 2016.

Trapping efficiency

Results indicated that captured weevils were significantly affected by trap types, where PICUSAN® trap gave the highest captured number during the experimental period, which lasted for 7 weeks, with 92 adult weevils captured, followed by the bucket trap with 75 weevils captured. Moreover, the combined effect of sugarcane honey, pheromone, ethyl acetate and pesticides gave more attractiveness than the other 4 tested combinations, with 78 adult weevils captured by this bait during the 8 weeks of the experiment, whereas the other four combinations captured 50, 37, 19 and 14 weevils. The least registered weevil's number was in sugarcane honey and pesticides. This might be due to the combined effect of such treatments. The efficacy of synthetic kairmone with different combinations on the attraction of weevils was also investigated. The best combination was water, aggregation pheromone, palm tissue and molasses (15%) in water. This combination collected around 246 adults during the 10 weeks period of the experiment. The mixture EtAc + EtOH (1:3) was able to boost pheromone and was almost as effective as the use of the complete bait. Ethyl acetate alone did not improve the attraction power for the aggregation pheromone. In addition, sex ratio was calculated and it was found that male:female ratio was 1:2.1.

Monitoring and early detection

Monitoring the activity of the RPW is essential for keeping a close watch on the establishment and subsequent build-up of the pest population. Early detection, on the other hand, is crucial to avoid the death of palms and is the key to the success of any IPM strategy adopted to combat this pest. Using of PICUSAN® trap with a bait of sugarcane honey, pheromone, ethyl acetate and pesticides or Water, aggregation pheromone, palm tissue and molasses 15% in water is recommended. Trapping adults of *R. ferrugineus* with food-baited traps to monitor the activity of the pest, or mass trapping of adults in the field has been recommended as a component of the weevil's IPM program in coconut plantations.

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الملخص

لينا، عبد المنعم، محمد كمال عبّاس، هاله عادل توفيق ومرسلم إبراهيم. 2019. كفاءة الطعوم الغذائية والمواد الجاذبة اللاصقة عن نوعية مصائد اصطياد سوسة النخيل الحمراء باستخدام مصائد فيرومونات تجارية ضمن مزارع النخيل في الإسماعيلية، مصر. مجلة وقاية النبات العربية، 37(2): 149-150.

كان الهدف من هذا البحث ... المصائد ... سوسة النخيل الحمراء ... PICUSAN® (وذلك ثلاث مرات ...) ... من: مولاس قصب السكر والفيرمون، ثلاث إلى ... ثلاث أعوام ...

كلمات مفتاحية: *Rhynchophorus ferrugineus*، حصاد، بيرومون، كيرمون

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Policies to control red palm weevil based on the recommendations of the Rome meeting

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Abstract

Al-Dobai, S. 2019. Policies to control red palm weevil based on the recommendations of the Rome meeting. Arab Journal of Plant Protection, 37(2): 151-152.

The strategies/policies to control red palm weevil (RPW) *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae) based on the recommendations of the Rome meeting should include the following elements: (i) Regulatory/Phytosanitary system; (ii) Resources; (iii) Programme management; (iv) Stakeholders awareness and involvement; (v) Research and Development; (vi) Monitoring and Evaluation (M&E). Details related to these elements were presented and discussed.

Keywords: Red palm weevil, quarantine procedures, policies, management strategies, RPW scientific consultation.

Introduction

Red Palm Weevil (RPW) *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae) is a key pest of palms originating from South and South East Asian Countries that has significantly expanded its geographical and host range during the last three decades. Weak/challenging enforcement of quarantine procedures and difficulties in the early detection of RPW-infested plant materials are considered key factors behind its rapid and constant spread. Although, several control means based on conventional and innovative technologies are available and have been utilized by countries to support their efforts, the results of control are not being satisfactory. The challenge to effectively manage RPW in most of countries can be also attributed to the lack of public awareness, well integrated polices and management strategies that involve all stakeholders, and are supported by adequate human and financial resources.

The framework strategy for eradication of red palm weevil that has been developed and endorsed at the FAO-CIHEAM scientific consultation and high-level meeting on red palm weevil management in March 2017, provides clear guidance for the effective policies to be adopted by countries to effectively manage and eradicate RPW.

RPW national strategies/policies should include these six key elements: (i) Regulatory/Phytosanitary system; (ii) Resources; (iii) Programme management; (iv) Stakeholders awareness and involvement; (v) Research and development; (vi) Monitoring and evaluation (M&E).

Regulatory/Phytosanitary System

The regulatory/phytosanitary system includes internal and external quarantine, and regulations. There are some common gaps and challenges in the most of national policies behind the failure to control RPW. Illegal/unregulated movement of infested palms within the country and between countries; lack of knowledge on the national phytosanitary legislation on RPW and interference in the imports/movement of planting material by higher ranked officials or other authorities are common challenges. Lack of availability of sources of trustful/certified palms (certified nurseries) within the countries; and poor implementation of phytosanitary (quarantine) measures for transfer of planting materials for new farms or gap filling in existing farm, between regions with in the country contribute to spread pf RPW. In addition; inadequate protocols and certification for export /import of ornamental and exotic palms; and lack of specific regulations/guidelines on phytosanitary measures to regulate the palm trade, especially at the entry points undermine the effective control of RPW.

Resources

Insufficient human or financial resources to cover labor-intensive control and high management cost are one of the obstacles hindering the implementation of national management program. The national polices should make provisions for sufficient qualified and committed human resources and operational financial resource.

Stakeholder’s Awareness and Involvement

Stakeholder’s awareness and involvement is crucial element for success the national RPW programme. The national policies should address these three points appropriately: (i) inadequate farmer and other stakeholder involvement in the control program; (ii) insufficient knowledge on the RPW socio-economic and environmental impacts and on the date palm farming systems and farmers organization; (iii) lack of public awareness on the risk associated with RPW in a broad sense.

The national RPW programme should have a clear-cut policy for farmers/stakeholder participation and engagement in RPW-IPM programs. The advantage of involving the farmers in the control program is that they present in the farm

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and can assist in detecting infested palms in early stage of attack that is the key action to control and eradicate the pest. Encouragement of the farmer participation should be supported by stakeholders mapping and needs analysis/studies to set a better knowledge of the socio-economic consequences of the RPW problem and of the farming systems in the infested areas; and to propose adapted solutions to facilitate the farmers' involvement. Strengthening extension programs and knowledge sharing mechanisms, and improved policies towards incentives to have a positive impact on a better marketing and incomes to farmers could be one of the effective measures.

Program Management

The national RPW control programs in most of the countries are operated by MoA, while in other countries the responsibility of controlling RPW is implemented by different institutions under the supervision of different ministries with very weak coordination. For efficient functioning and operation of the national RPW control programs the concerned Governments should make provisions to develop a framework for coordination between the national RPW control program and other relevant Governmental and non-Governmental institutions and farmer groups.

Government agencies working with RPW-IPM programs should establish defined linkages and coordination mechanism with cooperatives, NGOs and private sector to make the program more meaningful and effective. Involvement of oasis program in the RPW program in concerned countries is also recommended. Strong engagement and involvement of the law enforcement authorities and other stakeholder organizations is crucial for effective implementation of the phytosanitary measures and limiting the spread and risk of RPW.

Research and Development

The RPW national program should establish good cooperation with the research institutions and technology developers for sharing the information about the most recent results of research and innovations developed. Testing and validation of recent innovative techniques and methods for detection, surveillance, trapping techniques and management of the RPW that would facilitate the work and improve the effectiveness of the program.

Monitoring and Evaluation

Currently most of the national RPW-IPM Programs lack the component of the Monitoring and Evaluation (M&E). This has an adverse impact on the success of the programs, sustaining the positive results achieved and judicious use of resources. National strategies should be based on the Strategic Planning/Results Based Management approaches supported by a logical framework with clear key performance indicators and targets and M&E mechanism. It is recommended that a midterm and annual evaluation is carried out. It is vital to involve key stakeholders as much as possible in the evaluation process.

الملخص

الدبعي، شوقي. 2019. سياسات لمكافحة سوسة النخيل الحمراء استناداً لتوصيات اجتماع روما. مجلة وقاية النبات العربية، 37(2): 151-152.

إنّ الاستنتاجات والتوصيات التابعة لمكافحة سوسة النخيل الحمراء *Rhynchophorus ferrugineus* Olivier (غمدية الأجنحة *Coleoptera*، فصيلة السوسيات *Curculionidae*)، تبعاً لنظام ... : 1) لنظام ... ، 2) ... ، 3) ... ، 4) ... ، 5) للبحث ... ، 6) ... الالتزام ... بهذه الحشرة.

كلمات مفتاحية: سوسة النخيل الحمراء، ... ، سوسة النخيل الحمراء.

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Controversial aspects about red date palm weevil

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Abstract

Al Ayedh, H.Y. and A.M. AlJber. 2019. Controversial aspects about red date palm weevil. Arab Journal of Plant Protection, 37(2): 153-155.

This short note reviews and discuss three major red palm weevil (RPW) management controversies, mainly (i) the possibility of date palm fumigation by Aluminium phosphide, (ii) use of pheromone traps, and (iii) potential use of hyperspectral imaging for RPW detection. It also emphasizes the need for collaboration among various research groups working on red palm weevil management to develop effective methods to manage this pest.

Keywords: RPW, Control, management.

Introduction

Red palm weevil (RPW) *Rhynchophorus ferrugineus* (Olivier) (Coleoptera : Curculionidae) is indeed a global species infesting more than 30 palm species (Hussain *et al.,* 2013b). *Rhynchophorus* weevil is the only species spread from its original home in South Asia and Southeast Asia to many geographical places in the world. The time frame of RPW spread was different as from early 80s in the Gulf region until the year 2010 in California, USA.

Integrated pest management is the best solution for RPW suppression. However, invasion of RPW in different geographical regions over time raised numerous controversies regarding control options. Severity of the issue demands the development of a reliable method to successfully eradicate RPW infestations. Currently available red palm weevil management techniques, such as early detection, pheromone trapping, insecticide applications, quarantine and eradication of infested plants, face controversial and conflicting arguments not only from researchers in various disciplines, but also from farmers.

In this review, we have discussed three major RPW management controversies including 1) possibility of date palm fumigation by Aluminium phosphide; 2) pheromone trap usage; 3) potential of hyperspectral imaging for RPW detection.

Fumigation by Aluminium Phosphide

Aluminium phosphide is a cheap effective and commonly used pesticide (Gurjar *et al.,* 2011), and is mainly used to protect stored products from infestation with insect pests. It is a poisonous chemical among agricultural pesticides. The fumigation process by using Aluminium phosphide occurs while a gas is liberated when it comes in contact with either atmospheric moisture or with hydrochloric acid in the stomach. In Saudi Arabia, few farmers started the use of Aluminium phosphide to control RPW infestations in the field. Unfortunately, farmers are using a very basic and simplified method for its application. In brief, they are using highly puncturable plastic wrapping around the infested date palm trunk after inserting aluminium phosphide tablets. According to their theory, the fumigant penetrate into the trunk throw the opening of the date palm and kill the RPW infestations.

Resistance to pesticides is the change of sensitivity of the pest to the pesticides, which will results in failure of insecticide ability to kill the pest. In this way, pesticides will be no longer affecting the pest. Resistance controlled by genes in the insects population and carried out through generations. Upon exposure of pest to insecticides will force the resistance gene to rise, creating more resistant insect populations. Insect life cycle plays an important role in resistance emergence. Insects with short life cycle are more likely to develop resistance (Siegwart *et al.,* 2015), and help the resistance gene to be more affected. However, insect pests with longer life cycle will be less likely to develop resistance. The RPW life cycle is very long with two to three generations per annum (Abe *et al.,* 2009; Hussain *et al.,* 2013a, 2013b). Recently, a study from Pakistan reported 63-79 folds of resistance ratios (RRs) for phosphine, which is astonishingly very high RR without any previously published scientific record about the use of Phosphine in their country (Wakil *et al.,* 2018). Such results raises serious doubts and concerns about their suspicious findings. The methodology that was used, is generally practiced for stored grain pests. However, RPWs and stored grain pests are totally different and both require specific protocol for phosphine application. Surprisingly, they reported very high RRs from minor date palm growing areas instead of major date palm growing areas including Sindh and Baluchistan province of Pakistan. In this technological advanced era, such high RRs are lacking biochemical and molecular evidence for resistance development is not sufficient for such misleading claims.

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In another study, 8.72 RRs were calculated from RPW larvae fed on artificial diet incorporated with Cypermethrin in the Kingdom of Saudi Arabia (Al-Ayedh *et al.,* 2016). This study was performed on RPWs populations collected from main date palm growing areas of the Kingdom of Saudi Arabia. In addition, RRs were dually supported with biochemical analysis. However, Wakil *et al.* (2018) reported very high RRs (73.82) for the same insecticide (Cypermethrin) against RPWs from minor date palm growing areas. Such controversial published results which lacked molecular or biochemical evidence is questionable.

The deeper insights of phosphine mode of action suggest that the phosphine has an inhibitory effect on insect respiratory system, therefore, the effect is quick (Bond, 1984). Under field conditions, the chances for the RPW populations to develop resistance are minimal due to long life cycle. In addition, phosphine application does not require frequent application and single application is required to control RPW infestation. In summary, resistance should be regarded as country specific issue due to country specific insect pest invasion history, severity of target pest population, and agro-ecosystem variations. Overall, Aluminium phosphide has great potential to control the infestations of RPWs within the palms. However, application of Aluminium phosphide at each step demands specialized protocol customized for RPWs management.

Pheromone Traps

Pheromone traps remains the focus of most research investigations during the last few decades (Ávalos and Soto, 2015; El-Shafie *et al.,* 2011; Fiaboe *et al.,* 2011; Hamidi *et al.,* 2013; Hoddle *et al.,* 2013; Miguens *et al.,* 2011; Perez *et al.,* 1996). Pheromone traps are being used in date palm plantations since 1990s. Monitoring, mass trapping and early detection are the main uses of the pheromone traps. Like other methods, pheromone trapping also have merits and some disadvantages. Pheromone traps successfully used in some parts of the world. However, there are some complaints that these traps also attracted red palm weevils and increased infestations in these areas. Such situations did not lead towards ignoring pheromone trapping. Overall, pheromone traps are an important monitoring and mass trapping tool, which can never be neglected in a RPW management program.

RPW Detection

The last issue is the utilization of new detection methods such as hyperspectral imaging (HI), which collects and processes information from across the electromagnetic spectrum (Bannari *et al.,* 2016; Yones *et al.,* 2014). The goal of hyperspectral imaging is to obtain the spectrum for each pixel in the image of a scene, with the purpose of finding objects, identifying materials, or detecting processes. Hyperspectral imaging, can detect the water stress reflection from the plant canopy (date palm tree canopy). The water stress in the canopy might occur because of phloem and Xylem water loss, or RPW infestation or some other factors. However, the main criticism made is that this technique detects the reflection of stress at very late stage of RPW infestation. Furthermore, it has become very difficult to distinguish images of water stress and RPW infestations. Therefore, this area of research demands further exploration and technical sophistications.

In conclusion, many arguments can be raised but the control application should be implemented with the support of scientific evidence. The collaboration among various research groups working on red palm weevil management can be helpful to develop effective methods against this pest.

الملخص

آل عايض، حسين يحيى وأحمد محمد الجبر. 2019. قضايا جدلية حول سوسة النخيل الحمراء. مجلة وقاية النبات العربية، 37(2): 153-155.

تستعرض وتناقش هذه المذكرة القصيرة الثلاث قضايا رئيسة حول إدارة سوسة النخيل الحمراء؛ وتتركز أساساً حول: 1) إمكانية تدخين النخيل المصاب باستعمال فوسفيد الألمنيوم، 2) استخدام المصائد الفيرمونية، 3) إمكانية استخدام التصوير فوق الطيفي للكشف عن سوسة النخيل الحمراء. كما تشدّد على الحاجة للتعاون بين مختلف الفرق البحثية العاملة في مجال إدارة سوسة النخيل الحمراء لتطوير طرائق ناجعة لإدارة هذه الآفة.

كلمات مفتاحية: سوسة النخيل الحمراء، مكافحة، إدارة آفة.

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Date palm value chain development and the control of red palm weevil in Egypt

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Abstract

Abbas, M.K. and Th. Yaseen. 2019. Date palm value chain development and the control of red palm weevil in Egypt. Arab Journal of Plant Protection, 37(2): 156-157.

Egypt is ranked first in date palm production worldwide, with 16 million date palms. Red palm weevil (RPW) *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae) is considered the main pest of date palm in Egypt, and was recorded for the first time in this country in 1992 in date palm plantations of Sharkia and Ismailia Governorates. Infestation with this pest is now spread to all 26 governorates in Egypt, and the infestation rate ranges from 2% to 35%. FAO supported a technical support project (TCP/EGY/3603) on Date Palm Value Chain Development in Egypt, with main activities in the governorates of Siwa Oasis, El-Kharga, Paris Oasis, El-Dakhla, Al-Baharya Oasis, Aswan, Kefr El-Sheikh and Beheria Governorates. One of the project components was to provide assistance for RPW control. The project provided training for more than 3,000 persons (extension workers, farmers, and research workers) from Siwa Oasis, New Valley and Wahat Baheria oases, Aswan and Kefr El-Sheikh Governorates. Training sessions focused on the control of red palm weevil, fruit pests in the field and in storage, as well as on diseases that infect palm trees. The practical training was conducted at one of the palm farms. Based on visual inspection, trainees were able to identify different date palm pests and diseases. Methods of pest control, especially red palm weevil, were illustrated. Al-nakhalin 120 trainees from Siwa Oasis and New Valley (El-Khargaand El Dakhla direction) were given practical and theoretical training on all agricultural and control operations in 22 extension fields (20 fields in Siwa and 2 in El-Khargaand El-Dakhla). Control program implemented during different months ofthe year included: (i) control of pests that started to cause problems in recent years such as *Phonapatefrontasi*, *Oligonichusafrasiaticus* and *arlatoriablancherd*, (ii) biological control of date fruit pests, (iii) control of pests that affect dates during storage and processing. Training also included how to identify symptoms of different pest infestations. Five brochures (fruit pests in thefield, date palm diseases, storage pests,date palm borers in Egypt, and red palm weevil), in addition to a manualfor the control of red palm weevil were prepared. Scientific material for the training courses related to red palm weevil, frond palm borer and fruit stalk borer, disease and fruit pests behavior, common symptoms and control methods such as preventive measures, use of pesticides, light traps and biological control agents were also prepared. During project implementation, a report on the most important pests and diseases in the project work area was prepared, and included the following pests: *Oligonichusafrasiaticus, Parlatoriablancherdi, Arenipsessabell, Batrachedraamydraula, Ephesteacalidellaguer, EphestiaCautella, Rhynchophorusferrugineus, Oryzaephilussurinamens, Amitermisdesertorium* and *Coccotrypesdactyliperda.* In addition, a work plan for their control was also prepared.A questionnaire on pests and diseases to collect and analyse data from Siwa Oasis was also prepared. Furthermore, a work planto control date palm pests in Siwa oasis was prepared with assistance from an international expert. Training twenty trainees to train 2,000 farmers (TOT) on IPM ofdate palm pests was achieved. Furthermore, 1750 infested palm trees in Baharya and Siwa were treated using gasoline drills.Field experiments on integrated RPW management were implemented, using aggregation pheromone traps, injection of pesticides in infested palms with continued pest monitoring.

Keywords: Red palm weevil, control, date palm, value chain, training.

الملخص

عباس، محمد كمال وثائر ياسين. 2019. تطوير سلسلة القيمة للتمور ومكافحة سوسة النخيل الحمراء في مصر. مجلة وقاية النبات العربية، 37(2): 156-157.

احتلت مصر المرتبة الأولى في إنتاج العالم مع 16 مليون نخلة. تعدّ سوسة النخيل الحمراء *Rhynchophorus ferrugineus* Olivier (فصيلة السوس *Curculionidae* التابعة لرتبة غمديات الأجنحة *Coleoptera*) الآفة الرئيسية للنخيل في مصر، حيث سجلت أول مرة في مصر عام 1992 في مزارع نخيل البلح بمحافظتي الشرقية والإسماعيلية. وتنتشر الإصابة حالياً في 26 محافظة في مصر بنسبة إصابة تتراوح ما بين 2% إلى 35%. قدمت منظمة الأغذية والزراعة مشروع دعم تقني بتطوير سلاسل القيمة للتمور في مصر (TCP/EGY/3603)، وتركّزت الأنشطة الرئيسية في: واحة سيوة، الواحات البحرية، واحة باريس، واحات الداخلة والخارجة، ومحافظات: أسوان والبحيرة وكفر الشيخ. كان أحد مكونات المشروع هو تقديم المساعدة في مكافحة سوسة النخيل الحمراء. قام المشروع بتدريب أكثر من 3000 متدرّب (من العاملين في مجال الإرشاد الزراعي، والمزارعين، وعاملي البحوث الزراعية) في كلّ من واحات: سيوة والوادي الجديد والبحيرة، ومحافظتي كفر الشيخ والبحيرة. وتركّزت جلسات التدريب حول مكافحة سوسة النخيل الحمراء وآفات الثمار في الحقل وأماكن التخزين فضلاً عن الأمراض التي تصيب أشجار النخيل. وتم في التدريب العملي في إحدى مزارع النخيل، حيث تمكن المتدربون من خلال الفحص البصري من التعرف على آفات وأمراض النخيل المختلفة. كما تم توضيح طرائق مكافحة الآفات ولا سيّما سوسة النخيل الحمراء. كذلك فقد تلقّى 120 من المتدربين النخّالين في واحة سيوة والوادي الجديد (الواحة

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الخارجة والداخلة (تدريبات نظرية وعملية شملت جميع العمليات الزراعية وطرق المكافحة وذلك ضمن 22 حقل إرشادي (20 حقلاً في سيوة و2 في الخارجة والداخلة). تضمّن برنامج المكافحة المنفّذ خلال شهور السنة المختلفة من (المكافحة الآفات التي بدأت تسبب مشاكل خلال السنوات الأخيرة مثل *Oligonichusafrasiaticus*، *Parlatoriablancherdi*، *Arenipsessabell*، *Batrachedraamydraula*، *Ephesteacalidellaguer*، *EphestiaCautella*، *Rhynchophorusferrugineus*، *Oryzaephilussurinamens*، *Amitermisdesertorium* و *Coccotrypesdactyliperda* (المكافحة الحيوية لآفات ثمار النخيل؛ 3) مكافحة الآفات التي تؤثر على التمور أثناء التخزين والتعبئة. كما شمل التدريب كيفية تحديد أعراض الإصابة بالآفات الحشرية المختلفة. وقد جرى إعداد 5 نشرات إرشادية/بروشورات (آفات الثمار في الحقل، أمراض نخيل التمر، آفات المخازن، حفارات نخيل التمر في مصر، سوسة النخيل الحمراء) بالإضافة إلى دليل حول مكافحة سوسة النخيل الحمراء وقد تمّ إعداد المادة العلمية لدورات تدريبية حول سوسة النخيل الحمراء، حفار سعف النخيل، ثاقبة العراجين، سلوك آفات وأمراض الثمار، الأعراض الشائعة للإصابة وطرائق المكافحة (مثل: العمليات الوقائية، استخدام المبيدات، المصائد الضوئية، عوامل المكافحة الحيوية).

خلال فترة تنفيذ المشروع فقد تمّ إعداد تقرير عن أهم الآفات والأمراض في مناطق عمل المشروع، وقد شملت الآفات التالية: سوسة النخيل الحمراء يليها دودة البلح الكبرى والصغرى ثم آفات المخازن وثاقبة نواة البلح فضلاً عن تجهيز خطة عمل لمكافحتها. وجرى إعداد استبيان لجمع وتحليل البيانات حول أهم الآفات والأمراض التي تصيب النخيل في واحة سيوة؛ وعلاوة على ذلك فقد وضعت خطة عمل لمكافحة سوسة النخيل الحمراء في تلك الواحة بمساعدة أحد الخبراء الدوليين. وكذلك تمّ تدريب 20 متدرباً ليقوموا بدور مدرب لتدريب 2000 مزارعاً بهدف تدريب المدربين على تطبيق نظام المكافحة المتكاملة لآفات النخيل. وعلاوة على ذلك فقد عولجت 1750 شجرة نخيل مصابة في الواحات البحرية وسيوة باستخدام نظام الحقن الذي يعمل بالبنزين. ونُفّذت تجارب حقلية حول المكافحة المتكاملة لسوسة النخيل الحمراء باستخدام مصائد الفيرمون التجميعي وحقن النخيل المصابة بالمبيدات الكيميائية ومتابعة رصد الآفة.

كلمات مفتاحية: سوسة النخيل الحمراء، مكافحة، نخيل التمر، سلسلة قيمة التمور، تدريب.

The effect of preventive measures in reducing red palm weevil infestation

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Abstract

Abbas, M.K. 2019. The effect of preventive measures in reducing red palm weevil infestation. Arab Journal of Plant Protection, 37(2): 158-158.

The red palm weevil (RPW) *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae) is a palm borer native to South Asia, recorded in Egypt in date palm plantations of Sharkia and Ismailia governorates in 1992. The infestation at present is distributed all over the country including 26 governorates. A survey was conducted in Bahria oases, Giza governorate in Egypt in two successive years 2016 and 2017 to determine the red palm weevil infestation rate in 10000 palm trees. During the first year of study 2016, results indicated that the total infestation rate reached 21% (2100 palm trees), with 41 % (861 palm trees) of infested palm trees had air offshoots, whereas 20.2 % (430 palm trees) of infested palm trees had a large number of offshoots. On the other hand, 19.8 % of infested palm trees did not have offshoots, however, in orchards with drip irrigation system for comparison, the observed infestation rate was 5 % only (105 palms). Moreover, in case of flood irrigation system, the observed infestation rate was relatively higher (14 %). During the second year of the survey (2017), horticultural practices were applied including removal of aerial offshoots, in addition to pesticide spray with chlorpyrifos at a rate of 3 ml per liter of water which resulted in reducing infestation rate to 9%. It could be concluded that preventive measures can reduce pest incidence by 80.2%, in comparison with untreated areas, where pest infestation increased four times.

Keywords: Red palm weevil, aerial offshoots, infestation rate, chemical spray.

الملخص

عباس، محمد كمال. 2019. تأثير التدابير الوقائية في الحد من الإصابة بسوسة النخيل الحمراء في النخيل. مجلة وقاية النبات العربية، 37(2): 158-158.

تعدّ سوسة النخيل الحمراء Olivier *Rhynchophorus ferrugineus* (فصيلة السوس *Curculionidae* التابعة لرتبة غمديات الأجنحة *Coleoptera*) من ثاقبات النخيل المستوطنة في جنوب آسيا، وقد سجلت في مصر ضمن مزارع نخيل التمر في محافظتي الشرقية والإسماعيلية عام 1992؛ وتنتشر الإصابة حالياً في جميع أنحاء البلاد لتشمل 26 محافظة. أجريت دراسة في الواحات البحرية ومحافظة الجيزة في مصر على مدار عامين متتاليين 2016 و2017 لتحديد نسبة انتشار الإصابة بسوسة النخيل الحمراء في 10000 نخلة. بينت نتائج السنة الأولى (عام 2016) للدراسة أنّ النسبة الإجمالية للإصابة بلغت 21% (2100 شجرة نخيل)، وأنّ 41% منها (861 نخلة) كانت أشجارا مصابة ذات فسائل هوائية في حين أنّ 20.2% (430 نخلة) من أشجار النخيل المصابة احتوت على عدد كبير من الفسائل، بينما 19.8% من أشجار النخيل المصابة لم تمتلك أيّ فسائل هوائية. ومن جهةٍ أخرى، لم تتجاوز نسبة الإصابة العشرة 5% (105 نخلة) في البساتين التي تعتمد نظام الري بالتنقيط؛ إلّا أنّه وبالمقارنة فقد بلغت هذه النسبة 14% في حالة نظام الري بالغمر. وجرى خلال السنة الثانية للدراسة (عام 2017) تطبيق ممارسات البستنة التي اعتمدت على إزالة الفسائل الهوائية فضلاً عن رش النخيل المصاب بمبيد الكلوربيريفوس بمعدل 3 مل/لتر ماء حيث أدّى هذا الإجراء إلى انخفاض الإصابة حتى 9%. ومما سبق، يمكن الاستنتاج أنّ بمقدور الإجراءات الوقائية تخفيض الإصابة بالآفة بنسبة 80.2% مقارنةً بتلك في المناطق غير المعاملة والتي زادت الإصابة فيها حتى أربعة أضعاف.

كلمات مفتاحية: سوسة النخيل الحمراء، الفسائل الهوائية، معدل الإصابة، الرش الكيميائي.

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Importance of field operations for reducing red palm weevil (RPW) infestation on date palm

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Abstract

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Date palm tree is known to be very sensitive to field operations. The production and health of the tree are relative to the attention of the growers. Several field operations, including the choice of offshoots, spacing, fertilization, irrigation, fruit thinning, leaf pruning, and harvesting are important field practices. Cultivation operations, if well conducted, can reduce pest infestation on date palm tree and fruits, ameliorate the health of date palm tree and its production. It is essential to adopt the best practices to avoid many fungal and pest's infestations and reduce the loss of date palm production up to 30-40%. Red Palm Weevil (*Rhynchophorus ferrugineus*) is spread rapidly from East to West during 30 last years and was reported in several date-producing countries in the region. Studies carried out in date palm cultivation area confirmed that the date palm farming practices adopted, the variety planted, method of irrigation (flood/drip), palm density, crop and field sanitation, frond pruning, and offshoot removal, significantly impacted the establishment and subsequent infestation level due to red palm weevil on date palm.

Keywords: Date palm, pest management, best agricultural practices, RPW.

Introduction

Date palm still playing a major role in the agriculture activity and food production in dry areas. Many challenges are facing date palm: Climate change, environmental stress (soil fertility, water and soil salinity) and the invasive pests (ICARDA, 2016). Red Palm Weevil (*Rhynchophorus ferrugineus*) is one of the major pests of date palm, spread rapidly in several date-producing countries and Canary palms (*Phoenix canariensis*), especially in the Mediterranean basin.

RPW was spread further mainly through infested ornamental gardening and farming planting transported offshoots. Cultivation operations, if well conducted can reduce the infestations of date palm tree, ameliorate the health of the palms and reduce the loss of date palm production around 30-40%. When no precautions were observed when selecting offshoots, close spacing, no proper fertilization use, shortage in irrigation water, no fruit thinning and leaves pruning, and lack of proper harvesting are considered poor field practices. This paper summarizes the importance of best agricultural practices to reduce date palm tree and dates infestation by pests, especially RPW.

Choice and Handling of Offshoots

The main way to propagate date palm is still by offshoots. Major dangerous infestations are related to the origin of offshoots. RPW is an example of pests that spread through plants exchange and transfer between regions in the same country and inter-countries and continents (Faleiro *et al.,* 2006).

When establishing date palm plantations, it is important to pay attention to the origin of offshoots. One should ensure that they are free from pests, especially RPW. When there is doubt about pest's presence, it is necessary to disinfest the offshoots. National programs should implement an easy and fast exchange of plant genetic material without any risk of diseases and pests spread. Many authors reported that the exchange of offshoots is the main responsible way of spreading RPW in North Africa and the Mediterranean region (Figure 1).

Planting Density

The most traditional plantations in Middle East and North Africa are not widely spaced and not planted in straight lines. The practice of removing offshoots from the date palm mother stem is not always well-practiced. This complicates cultivation and protection interventions and facilitate infestation by pests, especially RPW. In well managed orchards, offshoots are removed at 3-4 years' age to maintain single stem trees.

Spacing and properly designed plantations can facilitate cultural practices, mechanization and spraying pesticides to combat pests when needed. When establishing modern farms, it is preferable to plant offshoots in straight rows and maintain a minimum 8x8 meters spacing, that is 156 palm trees per hectare (Ben Salah, 1999).

Cultivation Operations

Studies carried out in date palm cultivation area proved that farming practices adopted, the method of irrigation (flood/drip), plants density, crop and field sanitation, frond pruning, and offshoot removal, etc. have significant reduction in infestation of pests, especially RPW in the date palm plantations (Ben Salah, 2018).

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Figure 1. Offshoots handling and transportation.

Irrigation and Fertilization

Irrigation is necessary to date palm for optimal vegetative growth and good fruit quality. More water quantity is necessary in many places where the subsoil water is too saline for date palm, and irrigation keep down the salt when the surface irrigation water is soft and plentiful. However, surface irrigation techniques (flood water supply) can affect the date palm trunk and facilitate hibernation of pests.

Flood irrigation is still carried out in major plantations. This practice facilitate infestation by pests and fungi carried by irrigation water. It facilitates also the RPW entry in the date palm trunk. Frequent watering causes offshoot damage and create adequate conditions for pests to survive in the bottom of the date palm stem (Liebenberg and Zaid, 2002).

New sub-surface irrigation methods are developed and have the advantage of saving water resources. Many subsurface techniques are being investigated. The sub subsurface irrigation can avoid the development of weeds in the base of date palm tree and hibernation of pests, thus improving the date palm trunk health (Dewidar *et al.*, 2016) (Figure 2).

Fertilization is necessary for the date palm to improve over-all plant growth, extended leaf longevity and improves date palm yield. Nutrient deficiency can affect the date palm tree growth and symptoms can be easily observed. Good date palm health can reduce the infestations by insects and pests. It is advisable to apply the organic and phosphate fertilizers as one application deep in the soil. Nitrogen and potassium elements should be divided into 3-4 applications, starting at the beginning of flowering season (January-February) and repeated every 2 months thereafter until date harvesting.

Organic fertilizer is one of the most important sources of infection when it is not thermally treated. Insect eggs and larvae can be carried by fertilizer. Organic fertilizer must be thermally treated to ensure its safety from the pest's larvae and eggs. It is recommended to add 5-10 kg/tree annually. This quantity can vary depending on soil fertility (El Bekr, 1972; Klein and Zaid, 2002).

When adding mineral fertilizer, it is very important to be mix it properly with the soil. Some farmers broadcast fertilizers on soil surface and leaving it without mixing, which leads to great loss of nutrients through volatilization and percolation. Proper fertilization with major and minor elements can produce healthy and productive plants and reduce pest's attack.

Date palm Crown Operations

Pollination - Date palm trees are dioecious having male and female separate plants. Artificial pollination is essential for the completion of date palm fruit setting for optimum production. The male flower produces pollen, which is transferred to the inflorescence of the receptive female plant. Developed techniques for dry and liquid pollination can help to control the date palm health and avoid transfer of pests via pollination.

Dry and liquid pollination use hand and machine dusters or spraying machine from ground surface, without climbing the tree (Figure 3). Both techniques use extracted pollen (Ben Salah and El Marzooqi, 2000; Shabana *et al.*, 1985). Extracting pollen from male bunches can reduce the infestation of the bunch and can reduce the transport of insects from the male (pollinator) to the female date palm tree. In dry pollination, pollen is mixed by talc or flour. In liquid pollination, pollen is mixed with water. Both methods can reduce pests transport and bunches infestation.

Date palm liquid pollination recently developed proved to be a good technique for improving fruit setting rate, save time, reduce cost and consequently improve dates quality. In addition, using liquid pollination technology reduce labor costs and risk of laborers climbing accidents. The economic evaluation of the liquid pollination shows reduction of more than 50% of the operation cost. The technique is being successfully disseminated to all GCC countries within the project (Ben Salah and Al-Raissi, 2017).

The other advantage of liquid pollination is reducing the risk of transmission of pests carried by the male bunch to the female date palm tree, especially by inflorescence rot caused by *Mauginiella scattae* Cav., *Fusarium moniliforme* and *Thielaviopsis paradoxa*. The liquid pollination can be improved using pollen extraction devices which help adopting the new technology.

Figure 2. Sub-surface irrigation system.

Pruning- Pruning of date palm means removal of dead or nearly dead leaves and their bases when they also dried out. Is also possible to remove, green but broken leaves, and those attacks by serious pests.

Regular pruning and sanitation of date palm growing areas are critical for achieving prevention of pest infestation and disease infection. All dead leaves should be removed from the trees. To not provide a point of entry for pests, leaves should be cropped at the leaflet insertion area and the pruned area should be treated with pesticides. Pruning tools should be kept clean and disinfected as they can spread the fungal disease black scorch. This disease affects the flower and fruit strands which become deformed and causes terminal bud and trunk rot. It can eventually kill the trees (Dowson, 1982).

This operation aims also to facilitate cultivation operations: pollination, fruit thinning, bunch pending and dates harvesting (Hussain *et al.,* 1984). Dead leaves and leaf bases growing up to the lower end of fruit bunch must be removed after harvest, as they don't drop off naturally.

This operation is not practiced by many growers because of the difficulty of climbing the date palm tree. Mechanization is now providing means to facilitate pruning without climbing date palm tree. Date palm leaves can be used for many different purposes. When moving leaves from region to region, attention must be not to spread pests such as date palm scale: *Parlatoria blanchardi* L. (Nixon and Carpenter, 1978).

When pruning date palm, attention is needed to use good materiel for cutting leaves and frond bases (Kernef). It is also recommended to select the proper time of pruning and practice it during the period of low insects and RPW activities.

Figure 3. Date palm liquid pollination.

الملخص

بن صالح، محمد. 2019. أهمية العمليات الحقلية في الحدّ من إصابة نخيل التمر بسوسة النخيل الحمراء. مجلة وقاية النبات العربية، 37(2): 159-162.

تعرف أشجار نخيل التمر بحساسيتها العالية لعدم الانتظام في الري مع مدى تحملها للجفاف. تتعدد العمليات الزراعية التي تحتاجها أشجار النخيل، مثل التقليم والتلقيح والتسميد والري. لذا فإن إتقان هذه العمليات يساعد في الحد من الإصابة بالآفات وبخاصة حشرة سوسة النخيل الحمراء. تعد سوسة النخيل الحمراء Rhynchophorus ferrugineus Olivier من أخطر الآفات التي تصيب أشجار نخيل التمر حيث تتسبب في فقد يصل إلى 30-40%. انتشرت سوسة النخيل الحمراء من الشرق إلى الغرب خلال الثلاثين سنة الأخيرة. إن العمليات الحقلية المتبعة في زراعة النخيل، مثل طرق الري، والتسميد، والتقليم، تؤثر في مدى إصابة أشجار النخيل بهذه الحشرة. ويعتبر التطبيق السليم للعمليات الحقلية من أهم العوامل التي تقلل من الإصابة بسوسة النخيل الحمراء في أشجار نخيل التمر.

كلمات مفتاحية: نخيل التمر، دارا آفة زراعية، الممارسات الزراعية، سوسة النخيل الحمراء.

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Management of the red palm weevil *Rhynchophorus ferrugineus* (Olivier) using sustainable options in Saudi Arabia

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Abstract

Ali-Bob, M. 2019. Management of the Red Palm Weevil *Rhynchophorus ferrugineus* (Olivier) using sustainable options in Saudi Arabia. Arab Journal of Plant Protection, 37(2): 163-169.

Adhering to sustainable date farming practices in Al-Mohamadia farm in Al-Kharj region of Saudi Arabia has resulted in increased date fruits production by 2 fold in a 3 year time span from mature date palm trees grown on sandy soils and employing modern irrigation systems. The quality of date fruits has improved dramatically. The irrigation regime adopted resulted in enhanced water use efficiency and had a positive impact on date yield and fruit quality improvement. Among 20 date palm cultivars grown in Al- Mohamadia farm, 'Sagae' cultivar and male trees from different age groups were found to be more susceptible to RPW infestations. On-farm management practices of date palm pests particularly the notorious red palm weevil *Rhynchophorus ferrugineus* (Olivier) is presented. Control efforts against the RPW focused on the use of a blend of tactics including visual inspection and pheromone trapping, prevention and suppression through field sanitation, cultural practices, mechanical methods, eradication of severely infested palm trees, and chemical injection of Emamectin benzoate insecticide, which has shown good and long lasting effect. *Steinernema carpocapsae* (Weiser) nematodes alone or in combination with a local strain of *Beauveria bassiana* Bals. using trunk injections to control RPW showed mixed results. Some of red palm weevil management challenges, from a farmer's perspective were discussed.

Keywords: Date palm, red palm weevil, *Rhynchophorus ferrugineus,* IPM.

Introduction

The date palm, *Phoenix dactylifera* L. (Arecales: Arecaceae) trees are an important economic resource for many communities particularly in the Middle East and North Africa. Palms provide great cultural, social and environmental value. In Southern Europe, exotic palm trees are an essential component of the urban landscape. The Arab Region dominates in date production and trade. About 75% of the global area of 1.35 million ha under date palm is in the Arab Region (FAOSTAT, 2016). The Arab Region produces more than 75% of the world production of 8.46 million Tons of date. However, the date palm sector faces many production and marketing constraints including pests and diseases. El-Shafie (2012) enlisted 112 species of insects and mites associated with date palm worldwide. Losses in global production of dates have been estimated at 30% due to pests and diseases (FAOSTAT, 2013).

Date palm is very important in the socio-economy of people in Saudi Arabia. In 2015, the total tree count in Saudi Arabia was 28,570,804 grown in 123,301 farm holdings in an area of 107,281 Ha (General Authority for Statistics, KSA, 2015). Saudi Arabia is reported to have over 400 date palm cultivars of which 25 are important (Anonymous, 2006; Ashraf and Hamidi Esfahani, 2011). Dates production of Saudi Arabia averaged 970,000 tons during 2007-2016 (FAOSTAT, 2016). In 2016 Saudi Arabia exported 116,993 tons of dates worth aroud 141 million USD representing 9.8% of total value of global date exports (UN comtrade, 2018). In the National Transformation Program of Saudi Arabia's Vision 2030, the Kingdom is targeting a sales volume of about USD 2.45 billion (Vision 2030) to be achieved through sustainable development of the date palm value chain.

The Red Palm Weevil (RPW), *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae) is the most destructive pest of palms. FAO has designated it as category-1 pest on date palm in the Middle-East. It has a wide geographical and host range causing widespread damage to some 40 palm species in diverse agro-ecosystems worldwide (Anonymous, 2013). It has currently been reported in 45 countries (Faleiro and Al-Shawaf, 2018). *R. ferrugineus* was first reported in AlQatif in the Eastern Province of Saudi Arabia in 1987 (Abozuhairah *et al*., 1996). The effects of the RPW and the measures required to eradicate and control it are having significant socio-economic and environmental impacts on the palm production communities worldwide. The annual loss in six Gulf countries due to eradication of severely infested palms has been estimated to range from US$ 5.18 million to US$ 25.92 million at 1 and 5% infestation, respectively (El-Sabea *et al.,* 2009). Saudi Arabia's vision 2030 program is targeting to bring the level of RPW infestation from currently estimated 10% to 1%. Toward this end the Ministry of Environment, Water and Agriculture of the Kingdom of Saudi Arabia (MEWA) has embarked on an intensive nationwide RPW management program.

Date Palm Crop Management Practices in Al-Mohamadia Farm

Al-Mohamadia model farm (MF) is a model date palm farm and a leading production and dates processing company in Saudi Arabia. The farm is located in Al Kharj region, about

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60 km to the south of the capital Riyadh. MF has around 30,000 mature date palm trees comprising 20 date palm cultivars, including ‘Khalas’, ‘Sagae’, ‘Khodri’, ‘Nabtat Saif’, ‘Nabtat Sultan’ and ‘Hilali’. The dates are grown in sandy loamy soil with relatively elevated salinity level. Soil pH ranged from 7.1 to 8.2 and EC ranged from 3 to 14 ms/cm. The $CaCo_3$ content was relatively high (10-20%). The water quality is of the second degree with TDS ranging from 986 to 2,500 and pH of around 7.5 which was suitable for date palm production. MF dates are produced in accordance with optimized technical procedures and modern date palm technical operations.

MF adopts standard husbandry and GAP practices and site specific management practices in fertilization to maintain soil fertility, manage pests and apply modern irrigation systems to enable date production at high yield and quality specifications. Standard date palm ground and crown technical operations i.e. spiking, traditional pollination, fruit bunch thinning, offshoots removal, leaf and trunk pruning, bunch lowering and support, fruit bunch bagging, harvesting, sorting and storage were properly performed.

MF adopts a drip irrigation system and since 2013 implementing a watering regime that takes in consideration the factors of climate, soil type, tree age, variety and crop developmental stage. MF irrigation regime considers multiple measures including less irrigation time/tree but more irrigation frequency, particularly in farm blocks with sandy soil, improved water distribution in tree basin by using more bubblers/tree basin, improved water retention in tree basin through the use of organic manure, adapted flexible watering regime throughout the season according to soil type, date palm cultivar, climatic conditions and fruit developmental stage. During the period 2013 to 2017, there has been a general trend of yield increase as irrigation volume increased (Table 1). Monthly water applied ranged from 4.0 to 14.4 cubic meters per tree. Applying up to 121 cubic meter per year per mature date palm tree had a great impact on fruit yield and has contributed positively to fruit quality thus more farm revenues. Although fruit quality is a function of multiple management practices including thinning regime and the fertilization program. During the period 2013-2017, WUE in MF ranged from 0.59 to 0.82 Kg/m^3. Water footprint has been reasonably low ranging from 1,222 to 1,701 m3/ton, while the revenue was high and ranged 1,140 to 1,460 USD/ton (Table 1). Apparently this is influenced by market date price which is a function of fruit quality in addition to other market dynamics. Prices of ‘Khalas’ date fruits which is the predominant cultivar in MF (61% of the number of trees and 60% of yield volume) has been generally declining in the reported period.

During the period 2014-2017, date palms in MF received an average of 1.2 units of nitrogen, 0.5 units of phosphorus and 1.4 units of potassium in addition to varying quantities of calcium, magnesium, sulphur and some other minor elements. These units were availed from multiple sources including compost, farm yard manures, urea, ammonium sulphate, DAP, potassium sulphate, magnesium sulphate, calcium nitrate and potassium nitrate in addition to various granular and soluble compound fertilizers including 16-8-16 and 12-12-17 and small quantities of micro and trace element nutrient mixes. The type and amounts of fertilizers applied differed from one season to another. A major fertilizer meal composed of 25-50 Kg of organic manure plus DAP, potassium sulphate and magnesium sulphate were applied (incorporated in the soil) in Nov-Dec. The balances of fertilizer recipes were distributed throughout the active growing season from March to July with significant part of the potassium units applied during mid to late ‘khalal’ stage.

In MF, the pest management program dealt with fighting the fruit worms, mainly the lesser date moth, *Batrachedra amydraula* (Meyrick) with one prophylactic application immediately after completion of fruit setting (March-April), using generic pyrethroids e.g. Deltamethrins, Cypermethrins, Alphacypermethrins, Betacyfluthrins and Lambdacyhalothrin insecticides. Mites, mainly the old world date mite *Oligonychus afrasiaticus* McGreg., was one of the most notorious pests which required timely intervention with an average of 2.5 applications in the season using Abamectins, Flufenoxuron, Fenbutatin oxide, Hexythiazox, Matrine, Spirodiclofen, Spiromesifen, chlorfenapyr and mineral oils. Some of these chemicals are banned and no longer approved for use in Saudi Arabia. Fruit stalk borer, Rhinoceros beetles (*Oryctes* spp.) and longhorn borer *Jebusaea hammerschmidti* Reich were of less importance and were controlled using light traps. Synthetic pyrethroids were seldom used against these borers.

Fruit spots and sporadic incidences of heart rots were not of significance and were rarely combated using tebecunazole and triademeonle fungicides. Chemical pesticides were used in an alternating way to cater for resistance development. Other date palm pests and diseases e.g. Dubas bug, *Ommatissus binotatus* Fieber, green pit scale, *Palmapsis phoenicis* Rao, carob moth, *Ectomyelois ceratoniae* (Zeller) were of least importance.

Table 1. Irrigation and water use efficiency in Al-Mohamadia farm during the period 2013-2017.

Year	Yield (Kg/ tree)	Water applied (m^3/tree)	WUE (Kg/m^3)	Water footprint (m^3/ton)	Revenue (1,000 USD/ton)
2013	46.92	60.00	0.78	1,279	1.35
2014	52.00	88.47	0.59	1,701	1.22
2015	87.84	121.39	0.72	1,382	1.20
2016	79.96	119.13	0.67	1,490	1.46
2017	90.84	110.98	0.82	1,222	1.14

Bunch decline disorder striking during late 'Khalal' stage have been occasionally recorded in some seasons, more particularly on 'Sukkari' and 'Sellaj' cultivars, especially in trees with heavy fruit set in high temperature seasons. Non-chemical weeding was performed during the period from November to May. Weeds were left untouched from June until end of date fruits harvest by end of October.

This practice proved to be helpful in modifying the date palm tree microclimate to mitigate the excessive heat during summer. The use of mechanical cultivators (two-wheel 10.7 hp tilling machine) for weeding proved to be useful. In addition to removal of weeds, soil aeration, the use of cultivators helped to incorporate organic material in the tree basin. Weeding using cultivators proved to be more efficient compared to manual weeding and has positively reflected in tree performance. Timely harvesting of date fruits once they are ready for picking, helped in reducing incidence of insect infestations. However, high insect infestation in late maturing cultivars e.g. 'Munifi' could not be avoided and the fruits had to be fumigated afterwards.

The adoption of improved irrigation, fertilization, pest management, technical crown operations, cultural practices and farm team motivation has led to achieving outstanding farm key performance indicators. The adopted measures resulted in increased date fruits production by more than two folds. Average date palm tree yield increased from 39.4 Kg in 2012 to 87.8 Kg and 90.8 Kg in 2015 and 2017 seasons, respectively (Table 2). The drop to 80.0 Kg/tree has been a result of a more rigorous fruit bunch thinning regime adopted in 2016 season. The quality of date fruits has also improved dramatically. The percentage of big fruits (Royal and Premium) increased from 33% in 2012 to 38%, 59%, and 55% in 2013, 2014, 2016, respectively (Table 2). The proportion of big fruits dropped to only 28% in 2015 and only 25% in 2017, apparently due to the significant increase in yield (Table 2) as a result of a relaxed thinning regimes in 2015 and 2017 seasons.

RPW Incidence and Management Practices in Al-Mohamadia Farm

R. ferrugineus can be managed by adopting an integrated pest management strategy including regulatory methods, behavior manipulation, chemical and biological control, crop and field sanitation, eliminating hidden breeding sites, manipulation of cultural practices (Al-Dosary *et al.,* 2016). Studies in Saudi Arabia have shown that the date palm farming practices adopted, the variety planted, method of irrigation, palm density, crop and field sanitation, frond pruning, and offshoot removal, significantly affected the establishment and subsequent infestation level of red palm weevil in date palm (Sallam *et al*., 2012). Periodic inspections, although laborious, time consuming and costly have been carried out for detection of damage symptoms and weevil presence in the crown, the stipe, among the offshoots and around the palm base. General tree decline and leaf yellowing symptoms were helpful indicators to direct the surveillance team to do closer inspections. The level of RPW infestation in MF blocks and within the same block appeared to be clumped rather than uniform or random. Regular inspection of palms to detect early infestations in order to take appropriate measures early is becoming increasingly important and is now known to be the most essential component of the IPM strategy against *R. ferrugineus* (Faleiro and Al-Shawaf, 2018). Pilot trials on the use of thermal imaging, hyperspectral and Lidar for RPW detection were conducted in MF during 2016-2017 in collaboration with TEC-IB co. of the Netherlands and the Saudi Technology Development and Investment Company (TAQNIA). Preliminary promising results have been obtained, however further optimization is required.

RPW accumulated infestation incidences were 2.83%, 2.41%, 2.42% and 2.14% in 2014, 2015, 2016 and 2017, respectively. 'Sagae' cultivar and male trees from different age groups were found to be more susceptible to RPW infestation compared to other date palm cultivars grown in MF. This could be due to some physical or chemical characteristics or due to the presence/absence of fungal endophytic communities. Al-Bagshi *et al*. (2013) reported that 'Khalas' is among the most preferred date palm cultivars for egg laying by RPW. Contrary to many reports that showed highest infestation in young age groups, we have recorded higher RPW infestations in MF blocks with age group of 35-45 years than in blocks where the tree age was about 22-25 years. In coconut and date palm, young palms less than 20 years old are mostly infested by RPW (Abraham *et al*., 1998; Faleiro, 2006) indicating that tissue hardness, which increases with palm age, may deter RPW attack. According to Khalifa *et al*. (2001), 6-10 years old palm trees were more susceptible to infestation as compared to any other age group. Date palms 16 and more years old, are more resistant to infestation. Farazmand (2002) and Al-Ayedh (2008) found that date palm cultivars with high sugar content enhanced RPW population.

Table 2. Al-Mohamadia farm: total date yield in Kg (2012-2017).

	2012	2013	2014	2015	2016	2017
Number of trees	30,995	30,780	30,464	30,222	30,017	29,837
Total yield (Kg)	1,220,060	1,444,144	1,584,181	2,654,568	2,400,078	2,710,487
Average yield/tree (Kg)	39.4	46.9	52.0	87.8	80.0	90.8
% Big fruits	33	38	59	28	55	25
% Small fruits	67	62	41	72	45	80

In MF, while RPW infestations occurred in tree trunks, however in 'Sagae' cultivar and male trees, infestations occurred mostly at the tree crown. The infestation rate of palm trees that warranted eradication ranged from 25% to 28% (Table 3). The proportion of severely infested date palm trees which were eradicated were higher in 'Sagae' and male trees compared to 'Khalas' and other palm trees in which infestations occured at the tree trunk. When infestation is in the trunk the recovery chances seemed to be higher. Abraham *et al*. (2000) found that eradication of severely infested palms detected in area-wide pheromone based RPW-IPM programs in the Al Hassa oasis of KSA from 1995 to 1997 to stabilize at around 20%, whereas the remaining infestations responded to treatment with insecticide. Infestation at the height of 0-100 cm. was significantly more as compared to infestation occurring at any other height. Infestation recorded higher than one meter, was negligible (Khalifa *et al*., 2001). In date palm, infestation mostly occured at the base of the trunk near the soil (Abraham *et al*., 1998; Sallam *et al*., 2012), whereas in *Phoenix canariensis* the crown of the palm is usually attacked making detection extremely difficult and challenging (Dembilio and Jacas, 2012). Relatively high level of infestations were recorded in block 14 in MF which happened to be adjacent to the dumping area for eradicated RPW stricken trees; suggesting the inefficiency of RPW control even after burning of dead trunks. This highlights the importance of burial of dead trees after complete burning and preferably shredding.

Chemical Control of RPW in Al-Mohamadia Farm

In MF, major pest management efforts were directed towards RPW. Newly infested trees when detected, were clearly marked, and immediately sanitized by mechanically eliminating reachable insects and infested/damaged trunk tissues. This is followed by spraying with an insecticide and sealing the wound with Gypsum. Treating with diesel following offshoot removal was also a practice followed in MF. Other preventive and curative chemical treatments including chemical spraying and drenching in water and trunk injection with systemic insecticides were carried out in MF. At least one prophylactic chemical spraying in Dec. and/or March were directed at the crown of 'Sagae' cultivar and male trees in which the RPW infestations occured at the tree crown. Chemicals used for frond and trunk spraying included Fipronil, pyrethroids and Thiamethoxam insecticides. During the period 2015-2016, RPW infested palms were treated with Imidacloprid insecticide drenched in the tree basin at the rate of 21 gm a.i./tree coupled with simultaneous spraying of palm leaves and trunk to take care of new infestations and pupating insects at the rate of 3.5 gm a.i./tree. This treatment was repeated three time per year in the same tree with a one month interval, usually carried out in Feb, Mar and April. Imidacloprid application by this method yielded around 90% efficacy, however this treatment regime proved to be laborious and costly. Preliminary trials in 2017 showed that single trunk injection using Imidacloprid at the rate of 15 gm a.i./tree yielded more or less similar results and protected the palms for up to three months. Stem injection of Imidacloprid has been reported to cause more than 90% mortality in young grubs for more than 2 months after treatment (Dembilio *et al*., 2015; Dembilio and Jaques, 2015).

During the period from Nov 2016 to Sep 2018 and following successful initial trials, single application of Revive® (Emamectin benzoate 4 ME) insecticide employing trunk injections have been adopted as the main curative chemical treatment. Revive ® was applied at low pressure at the rate of 50 ml/tree (undiluted formulation) administered in 4 holes drilled at the base of infested tree trunk. In MF, date palm trunk injection using Revive® have shown improved efficacy and long lasting PPW control up to 9 months after treatment. Following Revive® applications in 2017 and 2018, more RPW infestations were recorded in offshoots. Conventional aggregation pheromones and Electraps were used for mass trapping of RPW in MF. Pheromone traps at the rate of 2 traps per hectar were deployed in blocks with high weevil activity. Pheromone traps were placed away from farm borders to make sure that they do not contribute to attracting RPW from neighboring farms. Food baited pheromone traps are widely used to monitor and mass trap adult *R. ferrugineus* in date palm, where most weevil captures are females (Faleiro, 2006).

Non-Chemical RPW Control in Al-Mohamadia Farm

In MF there has been no introduction of new date palm planting material from outside the farm. RPW prevention and suppression revolved around field sanitation, cultural practices and mechanical methods. Crop and field sanitation is vital to curb the build-up of RPW population and to sustain the levels of success where the pest is controlled (Abraham *et al*., 1998; Al-Dosari *et al*., 2016). In MF, sanitation by mechanical elimination of infested palm tissues has been followed by prophylactic treatment of wounds and use of gypsum to seal sites of mechanical damage. Double ring irrigation basins were erected in some MF blocks to make sure that water not to be in direct contact with the base of the date palm trunk and associated offshoots, if any. Off-shoot removal is practiced as offshoots contact with mother palm trees may predispose the palm trees to RPW. Avoiding palm injuries was very crucial and sticking to concurrent protective spraying when doing stem pruning 'Takreeb' have been stressed in MF RPW management program. Severely infested palm trees which were beyond recovery were eradicated by burning.

Table 3. Number of date palm trees infested and eradicated due to the red palm weevil infestation in Al-Mohamadia farm during the period 2014 – 2017.

	2014	2015	2016	2017
No. of palm trees	30,464	30,222	30,017	29,837
No. of infested palm trees	861	728	726	640
No. of eradicated palm trees	242	205	180	165
% infestation	2.83	2.41	2.42	2.14
% eradicated palm trees	0.79	0.68	0.60	0.55

Non-chemical RPW control in Al-Mohamadia farm

In MF there has been no introduction of new date palm planting material from outside the farm. RPW prevention and suppression revolved around field sanitation, cultural practices and mechanical methods. Crop and field sanitation is vital to curb the build-up of RPW population and to sustain the levels of success where the pest is controlled (Abraham *et al*., 1998; Al-Dosari *et al*., 2016). In MF, sanitation by mechanical elimination of infested palm tissues has been followed by prophylactic treatment of wounds and use of gypsum to seal sites of mechanical damage. Double ring irrigation basins were erected in some MF blocks to make sure that water not to be in direct contact with the base of the date palm trunk and associated offshoots, if any. Off-shoot removal is practiced as offshoots contact with mother palm trees may predispose the palm trees to RPW. Avoiding palm injuries was very crucial and sticking to concurrent protective spraying when doing stem pruning 'Takreeb' have been stressed in MF RPW management program. Severely infested palm trees which were beyond recovery were eradicated by burning. Date palms in the late stage of attack exhibiting severe tissue damage (>30%) should be eradicated (Faleiro and Al-Shawaf, 2018). The entomopathogenic nematodes *Steinernema carpocapsae* (Weiser) alone or in combination with a local strain of *Beauveria bassiana* Bals. using trunk injections have been used in MF against the RPW and showed mixed results. It is important to further explore the potential of using these biological agents employing standardized protocols to consistently test and enable fair evaluation and judgement of their utility and true potential in the fight against the RPW under field conditions. Issues of formulation, delivery into to palm trees, mobility (if any) of entomopathogens inside tree trunk, persistence and the best time window for field application are some of the issues that need to be evaluated.

On farm RPW challenges in Al-Mohamadia farm

Even though significant progress was made in RPW management at MF, there are still a number of challenges that need to be addressed and they are as follows:

- Despite all efforts against RPW, there is still moderate efficiency of RPW management in Al-Mohamadia farm.
- Reinfestation of the same palm tree after treatment.
- The cost of RPW control in MF has been high and it is labor intensive.
- Application challenges, especially in case of trunk injections in large date palm plantations with high RPW incidence. The drilling, injection arrangements and sealing of holes are laborious.
- Delayed removal of severely infested palms and dispersal of insects en route to the dumping sites.
- Spread of infestation from not properly incinerated palm trees.
- Due to the cryptic nature of this pest, crown infestation in some cultivars proved to be challenging to inspection teams and symptoms were detected in an advanced stage when damage had already taken place and chances of recovery become low.
- Lack of a quick, cost effective and easy to handle device for early detection of RPW.
- The dissection of palm trees in trials and RPW control evaluations, has been laborious, time consuming and costly. Utilization of novel non-destructive early detection technologies are very much needed in this regard.
- Continuous replacement/servicing and inspection of the RPW conventional traps has been challenging.
- Lack of active and effective involvement of neighboring farmers in RPW control operations.
- Lack of effective natural/biological insecticides and thus more environmental and health hazard as a result of the frequent use of preventive and curative RPW insecticides.

Concluding Remarks

- In MF despite all RPW control efforts being exerted, the infestation levels are still high in some sections of the farm. The pest continues to inflict significant damage. This is partly due to presence of sources of infestation from neighboring farms. RPW are good flyers, they can fly up to 5 Km and are capable of long range dispersal (Avalos *et al*. 2014), thus capable of crossing borders and reaching from farms many kilometers away.
- During a four year span, RPW infestation rate in MF date palm blocks ranged from 0% to around 11%. Higher infestation rates were always recorded in blocks adjacent to neighboring farms and in one block adjacent to a dumping site, where eradicated palm trees are incinerated.

- It is important to train and motivate field workers to carry out inspections and monitoring of RPW infestations and carefully inspect trees with multiple offshoots and to avoid palm injuries.
- If 'Takreeb' is to be done at all, then it should be done at time of low RPW activity and concurrent spraying with effective insecticides has to be carried out effectively and without delay.
- RPW incidence seems to be higher than generally anticipated. Given the cryptic nature of RPW, we suggest using an arbitrary on-farm RPW infestation rate to reflect a more realistic estimation of RPW incidence by multiplying the actually detected RPW infestation level by 3.
- Date palm farmers work in isolation and there is a need for coordinated efforts through farmer cooperatives. There is a need for cooperation and coordination of efforts at all levels for development and implementation of a successful RPW IPM strategy.
- From a farmer's perspective we believe such an IPM strategy should utilize modern early detection technologies in addition to the use of an optimized attract and kill tool, while endotherapy treatments utilizing chemical/biological insecticides is to be adopted for controlling RPW in established infestations.
- It is important to establish propagation centers for dissemination of RPW free planting material of popular date palm cultivars in addition to adoption of phytosanitary and strict quarantine regulations. It is important to put in place effective modalities to ensure farmer and stakeholder participation in the RPW management programs.
- There is a need for quantification of the socio-economic impact of RPW and evaluation of the risks associated with RPW at the national level.

الملخص

الشعيبي، محمد. 2019. إدارة سوسة النخيل الحمراء *Rhynchophorus ferrugineus* Olivier باتباع خيارات مستدامة في المملكة العربية السعودية. مجلة وقاية النبات العربية، 37(2): 163-169.

أثمر الالتزام بممارسات الزراعة المستدامة للنخيل في مزارع المحمية الواقعة ضمن منطقة الخرج في المملكة العربية السعودية زيادة غلة حوالي الضعفين في كمية التمور الناتجة طيلة ثلاث سنوات متتالية من أشجار نخيل التمر البالغة المزروعة في تربة رملية طبقت عليها أنظمة الري الحديثة فتحسنت جودة ثمار التمر بشكل ملحوظ. وكان لنظام الري بالتنقيط نتائج ملموسة في تحسين كفاءة استعمال المياه بالمقارنة مع الري التقليدي في تحسين غلة التمر كمّاً ونوعاً. ومن بين 20 صنفاً من التمور المزروعة في مزارع المحمية، لوحظ أنّ كلاً من الصنف صقعي (Sagae) وأشجار النخيل المعمّرة كانت هي الأكثر حساسية للإصابة بسوسة النخيل الحمراء. تناقش هذه الدراسة أهمّ الممارسات الحالية لإدارة آفات نخيل التمر وخصوصاً سوسة النخيل الحمراء *Rhynchophorus ferrugineus* Olivier. ركّزت الجهود المبذولة لمكافحة سوسة النخيل الحمراء على اعتماد توليفة من التقنيات والتي تضمنت: المراقبة المستمرة والمصائد الفيرمونية والعلاج من خلال اتباع التدابير الوقائية للحدّ من الممارسات الزراعية والطرائق الميكانيكية كاستئصال أشجار النخيل المصابة بشدة والحقن الجذعي بمبيدات مثل إيمامكتين بنزوات والتي أظهرت فعالية جيدة وتأثيراً مديداً. تم استخدام الديدان الخيطية *Steinernema carpocapsae* (Weiser) سواء منفردة أو بدمجها مع عزلة محلية للفطر الممرض للحشرات *Beauveria bassiana* Bals؛ وقد أظهر حقن جميع أشجار النخيل لمكافحة سوسة النخيل الحمراء بهذه الممرضات نتائج مشجعة، كما نوقشت بعض التحديات في إدارة هذه الآفة من وجهة نظر المزارعين.

كلمات مفتاحية: نخيل التمر، سوسة النخيل الحمراء *Rhynchophorus ferrugineus*، برامج المكافحة المتكاملة.

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Overview of the gaps, challenges and prospects of red palm weevil management

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Abstract

Faleiro, J.R., M. Ferry, Th. Yaseen and S. Al-Dobai. 2019. Overview of the gaps, challenges and prospects of red palm weevil management. Arab Journal of Plant Protection, 37(2): 170-177.

The Red Palm Weevil (RPW) *Rhynchophorus ferrugineus* Olivier has emerged as a key pest of palms in diverse agro-ecosystems worldwide. RPW has its home in South and South-East Asia where it has been a major pest of coconut. Ever since it was reported on date palm in the Middle East during the mid-1980s, it has spread rapidly mainly through infested planting material. Recent reports of RPW invasion suggest that the pest is gaining foot hold in the Caucasian region where it is detected from Sochi in Russia and Abkhazia in the republic of Georgia and also from East Africa in Djibouti. The current RPW IPM programmes, based on pheromone/bait trapping among other techniques have been implemented with limited success. Gaps and challenges in almost all the components of the strategy, particularly with regard to early detection of the pest, developing and implementing phytosanitary measures, lack of farmer participation in the programmes and scarcity of data on socio-economic issues among several other factors have made RPW control and eradication extremely difficult. On the positive side, the pest has been eradicated in the Canary Islands and is approaching eradication in Mauritania. Eradication has also been obtained in various oasis in Oman but new introductions of infested palms have ruined these successes. The Food and Agriculture Organization of the UN during the Scientific and High Level Meeting on the Management of RPW in March, 2017 called for the urgent need to combat RPW by collaborative efforts and commitments at the country, regional and global levels to stop the spread of this devastating pest and formulated a framework strategy for eradication of RPW which aims to support efforts/programs of countries to stop its spread, to achieve a strong decline and if possible its eradication. This has led to the 'FAO Programme on RPW Eradication in the NENA Region' to intensify governance, monitoring, scientific research, capacity building and coordination. The program fosters the ongoing research on the applicable approaches of biological control and innovative detection and control methods. Furthermore, the 'FAO Global RPW management platform' aims mainly at monitoring the pest using mobile apps and GIS based techniques. This presentation highlights the gaps and challenges in the current RPW-IPM strategy with prospects for improving each component of the RPW-IPM program, based on a much better knowledge on the socio-economic situation and the participation of the farmers and other stakeholders.

Keywords: *Rhynchophorus ferrugineus,* area-wide management, regional, global, constraints, vision.

Introduction

The Red Palm Weevil (RPW) *Rhynchophorus ferrugineus* Olivier (Coleoptera: Curculionidae) is a key pest of palms that has expanded its geographical and host range during the last three decades, ever since it gained foot hold on date palm *Phoenix dactylifera* L. in the Middle-East during the mid-19980s (Faleiro, 2006; Giblin-Davis *et al*., 2013; Gomez and Ferry, 2002). Rhynchophorus palm weevils threaten agricultural areas and natural landscapes (Milosavljević *et al*., 2018) and RPW poses a major threat to palm species in diverse agro-ecosystems worldwide. Recently the Caucuses (Sochi in Russia and Abkhazia in Georgia-Faleiro, 2018) and East Africa (Djibouti: Personal communication from Mr. Yusuf Duhur on 16 June, 2018) have detected RPW on the Canary palm and date palm, respectively. The pest poses a major challenge to date palm farming in the Near East and North Africa (NENA) region which accounts for nearly 90 % of the global date production, threatening livelihood security of rural farming communities. RPW is known to move within national, regional and international boundaries mainly through infested planting material transported for farming and landscape gardening. This calls for the urgent development of quarantine protocols and strict implementation of phytosanitary measures, to restrict the spread of RPW and also to sustain control levels where the pest has been successfully controlled (Faleiro *et al*., 2012; Hoddle *et al*., 2013). Besides phytosanitary measures, the key to the success of any RPW control strategy is the early detection and treatment of infested palms. Currently detection of infested palms is done manually by visual inspections. A recent study (Pugliese *et al*., 2018) on the use of several early detection devices based on thermal imaging, digital camera, tree radar unit and densitometer, concluded that thermal cameras and densitometers hold promise for future RPW detection where detection accuracy levels were nearly 90 %.

Keeping in view the seriousness of the problem, the Food and Agriculture Organization (FAO) of the United Nations along with the International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM) organized a Scientific Consultation and High Level Meeting during March, 2017 wherein a multi-discipline and multi-regional strategy to combat RPW was proposed (http://www.fao.org/3/a-ms665e.pdf). Although, many control means based on conventional and innovative technologies are today in place, FAO attributes the failure to manage RPW in most of the countries to the lack of awareness and systematic and coordinated control actions or management strategies that involve all stakeholders, which is related to inadequate human and financial resources available to combat the pest.

http://dx.doi.org/10.22268/AJPP-037.2.170177

In general, the failure to control RPW is often not due to the lack of technology but is largely related to socio-economic and operational issues (Figure 1). Very few quantitative data are available on the economic and social impacts of the RPW, at the local or at the national level. To establish such data constitutes an urgent priority. It will allow first to justify by an analysis the cost/benefit ratio to control this pest and, secondly, to identify the weaknesses of the present control programmes and to elaborate socio-economic solutions (Abdedaiem *et al*., 2017). Eradication of the pest conceived as a long-term goal is a strategic mistake that is not sustainable. Hence, upon recording the pest, it is essential to quickly provide the necessary resources (human and material) for the control and eradication of RPW in an adequate and timely manner for the rapid control of the pest (Ferry *et al*., 2018).

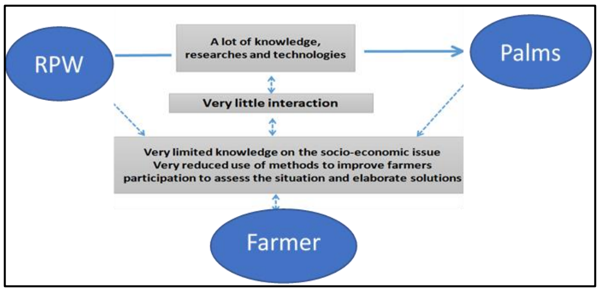

Figure 1. Socio-economic data at the local and national level on the impact of the RPW (Source: Ferry *et al*., 2018).

The current RPW IPM strategy was first tested in Saudi Arabia in date palm and proposed by Abraham *et al*. (1998). This strategy has evolved over the years (Aldobai and Ferry, 2017) and as illustrated in figures 2 and 3 is based on several components including detection of infested palm, pheromone trapping, chemical treatments, removal of severely infested palms, phytosanitary measures among other techniques; which has been implemented with limited success in several countries. The gaps and challenges in almost all the components of the strategy, particularly with regard to early detection of RPW, developing and implementing phytosanitary measures, lack of farmer participation in the programmes and scarcity of data on socio-economic issues, among several other factors, has made control and eradication of this lethal pest extremely difficult. On the positive side, the pest has been eradicated in the Canary Islands and is approaching eradication in Mauritania (Fajardo *et al*., 2017a and http://propalmes83.com/index.php/actualites2/105-en-mauritanie-nette-regression-du-charancon).

A recent report on *Rhynchophorus* palm weevils suggests that enhanced consideration should be given to exclusionary quarantine regulations, invasion monitoring, and eradication to prevent establishment and spread of *Rhynchophorus* spp. Furthermore, management strategies in the future need breakthroughs in surveillance, genetic modification of palm hosts, and new association of biological control (Milosavljević *et al*., 2018). During the Rome meeting in March 2017 the RPW-IPM strategy was deliberated thoroughly (http://www.fao.org/3/a-ms665e.pdf). The following is a summary of the major gaps and challenges in the current RPW-IPM strategy with prospects for improving each component of the RPW-IPM program (Table 1).

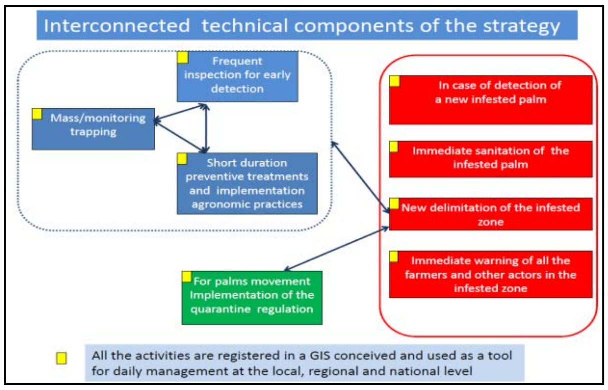

Figure 2. Interconnected components of the RPW-IPM strategy (Source: M. Ferry. http://www.fao.org/3/a-ms665e.pdf)

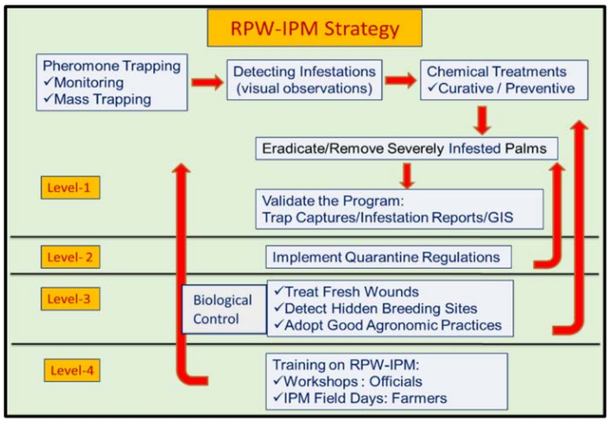

Figure 3. Operational details of the RPW-IPM strategy implemented at different levels (Updated from http://www.fao.org/3/a-ms665e.pdf)

Farmer Participation in RPW Management

Farmer participation in the RPW control programs in several Middle East countries is almost non-existing. Previous research suggests that for the efficient management of mobile insect pests in area-wide operations, farmer participation and cooperation is vital for the program to succeed (Yu and Leung, 2006). The challenge is therefore to enhance the involvement by farmers in the control of RPW in their farms and keep state support/participation in the program to the bare minimum. In this context it is essential to generate data on socio-economic aspects of RPW control through pilot studies on the participation by farmers in the RPW control program and also build capacities of farmers/ national staff on RPW control national/regional initiatives (FAO trust fund for NENA Region) so as to enhance farmer participation in the control of the pest through Farmer Field Schools (Abdedaiem *et al*., 2017; Aldobai and Ferry, 2017). It is pertinent to mention that besides building capacities of all stakeholders, increased awareness and extension campaigns on RPW management is essential in all the NENA countries to enhance farmer participation in the control program.

Table 1. Major gaps, challenges and prospects of the RPW-IPM strategy

Gaps, Challenges and Prospects	**Selected References**
Early detection, surveillance and monitoring	
Gap • Lack of a reliable, easy to use and cost effective RPW detection device. • Inadequate farmer/stakeholder participation in detection of RPW infested palms. • Guidelines to categorize palms in different stages of attack are lacking. • Surveillance and monitoring programs not standardized. ***Challenge*** • Develop a uniform protocol for visual inspection, surveillance and monitoring. • Improve farmer/stakeholder's involvement in detecting RPW infested palms. • Use of GIS platform to register the inspection/detection of infested palms. ***Prospect*** • Advanced early detection techniques (acoustics, thermal imaging, chemical signatures, laser induced breakdown spectroscopy, near infrared spectroscopy, biological and physiological indicators, sniffer dogs, remote sensing etc.) that are efficient, easy to use and low cost to be tested for their efficiency and cost effectiveness. • FAO initiative to establish a global RPW management platform that consists of the development of a mobile app tool for the collection and transmission of data on the inspection of palms. • Surveillance and monitoring of RPW standardized in the region and improved.	http://www.fao.org/3/a-ms665e.pdf Pugliese *et al*., 2018 Mankin, 2017; Soroker *et al*., 2017
Pheromone trapping/Semiochemical control	
Gap • Current technology is labor intensive and costly due to periodic servicing of the traditional traps. • In several countries RPW traps are serviced by the Department of Agriculture officials with no participation by the farmers. • Lack of systematic data collection and maintenance of the traditional trap. • Non-availability of a field worthy smart trap capable of transmitting weevil captures 24x7. • Insufficient scientific assessment of the new traps and lures. ***Challenge*** • Scientific assessment of efficient and cost-effective traps. • Improve farmer/stakeholder's involvement in servicing and maintain traps. • Incorporating long lasting synthetic kairomones/food baits to eliminate servicing required for the traditional trap. • Transmitting weevil capture data on a 24x7 basis through a smart and dry trap. • Improve the field longevity of pheromone lures. ***Prospect*** • Advanced semiochemical mediated systems involving Attract &Kill, Attract &Infect, Push &Pull etc., developed. • RPW pheromone trapping made efficient and cost effective.	Abraham *et al*., 1998; Vidyasagar *et al*., 2000; Elshafie and Faleiro, 2017; Al-Saroj *et al*., 2017; Soroker *et al*., 2015; Vacas *et al*., 2014
Preventive and curative chemical treatments	
Gap • Excessive use of preventive chemical treatments on a calendar schedule. • Dearth of efficient natural products for RPW treatments. • Insecticide resistance developing in RPW to commonly used insecticides. • Improper use of insecticides leading to contamination of the environment and food chain. • Insecticide residues in dates beyond the permissible limits hampering trade of dates. • Lack of standardized protocol to treat RPW infested palms in early stage of attack. ***Challenge*** • To involve and train farmers on the right use of pesticides. • To keep preventive chemical treatments to the bare minimum. • Develop a harmonized protocol for preventive and curative chemical treatments in date palm and ornamental palms. • Evaluate new natural products and biological control agents. • Involve and train the farmers on chemical control measures against RPW especially the proper and safe use of aluminum phosphide in curative treatment. • Efficient use of pressure injectors to treat RPW infested palms and their comparison with the simple diffusion technique. ***Prospect*** • A harmonized protocol for preventive and curative chemical treatments against RPW developed. • Safe biological control agents tested and deployed for RPW control as against the hazardous chemical treatments. • Capacities of farmers/national staff with regard to the use of preventive and curative treatments of RPW infested palms developed through national/regional initiatives (FAO trust fund for NENA Region).	Faleiro, 2006; Ferry and Gomez, 2014; Aldawood, *et al*., 2013; Ferry,2017; Al-Dosary *et al*., 2016; Milosavljević *et al*., 2018

Table 1. Cont…..

Gaps, Challenges and Prospects Early detection, surveillance and monitoring	Selected References
Removal (eradication) of severely infested palms	
Gap • Different protocols for the removal and disposal of severely infested palms. • Use of costly palm shredders to pulverize palms that are removed/eradicated. • Delayed removal of severely infested palms resulting in emergence/escape of adult weevils. • Escape of adult weevils on-route from the farm to shredding site during transportation of severely infested palms. ***Challenge*** • Involve and train the farmers to remove severely infested palms. • Develop a standard protocol that is cheap and easy to adopt for safe removal and disposal of severely infested palms in-situ (at the farm site). ***Prospect*** • A consistent protocol for eradicating severely infested palms developed. • Capacities of farmers/national staff built with regard to removal and disposal of severely infested palms.	Abraham *et al*., 1998; Faleiro, 2006; Al-Dosary *et al*., 2016; Milosavljević *et al*., 2018
Phytosanitary / Quarantine	
Gap • National/ regional phytosanitary /quarantine regulations against RPW are not adequately implemented. • Treatment protocols to treat palms prior to transportation and also after arrival at destination are not consistent. • Implementation of the regulations is weak due insufficient staff that is often not trained. • Certified planting material is difficult to get. ***Challenge*** • Spread awareness to involve the farmers and other stakeholders. • Develop phytosanitary/quarantine regulation against RPW and ensure implementation at the national, regional and international levels. • Availability of pest free palms through certified palm nurseries/ tissue culture laboratories. ***Prospect*** • Phytosanitary/quarantine regulations standardized at the national and regional levels. • Certified pest free planting material is produced. • Capacities of farmers/national staff with regard RPW quarantine measures built through national/regional initiatives (FAO trust fund for NENA Region).	Faleiro, 2006; Al-Dosary *et al*., 2016; Milosavljević *et al*., 2018; http://www.fao.org/3/a-ms665e.pdf
GIS/Periodic validation of the control program	
Gap • Data on the geo-reference localization of the palms, the RPW-IPM components and their evolution over time using GIS to elaborate maps and analysis of these data is lacking. • Periodic validation of RPW management programs at the local and national levels is lacking/inadequate. ***Challenge*** • Collect real time data on RPW management at the local, national level and the NENA region to serve as an effective early warning system. • Develop a mobile app to record geo-referenced data on RPW management. • Lack of adequately trained staff to use mobile apps/GIS for RPW management. ***Prospect*** • Real time data base and web portal for the management of RPW at the local, national and NENA Region developed. • A mobile app for android and iOS smart phones to record geo-referenced data at the field location on a standard form developed. • A training module for different categories of users of the tools (mobile apps, GIS, software) established. • Remote sensing for large scale monitoring for RPW infested plantations/palms carried out. • Periodic validation of the IPM program for judicious use of resources. • Capacities of farmers/national staff built with regard to the use of the mobile app to record and transmit RPW-IPM data resulting in efficient decision making (FAO trust fund for NENA Region/FAO global RPW management platform).	http://www.fao.org/3/a-ms665e.pdf Massoud *et al*., 2012; Fajardo *et al*., 2017b

Table 1. Cont…..

Gaps, Challenges and Prospects Early detection, surveillance and monitoring	Selected References
Biological control	
Gap • Known RPW biological control agents (fungi and nematodes) not adequately exploited for RPW control due to poor efficiency and sustainability in the field. ***Challenge*** • Deliver the biological control agent to the pest within the palm. • Increase the sustainability of the biological control agent particularly in the arid and hot climatic conditions of the oasis in the NENA region. ***Prospect*** • Effective parasites and predators in palm agro-ecosystems of the world against RPW identified. • The efficacy and sustainability of known and new RPW biological control agents tested and field validated through national and regional initiatives. • Capacities of farmers/national staff built with regard to biological control of RPW through national / regional initiatives (FAO trust fund for NENA Region).	Mazza *et al*., 2014; Hajjar *et al*., 2015
Agricultural practices	
Gap • The influence of agricultural practices on RPW infestation and its management receives very little attention from the farmer and other stakeholders. ***Challenge*** • Sensitize all stakeholders in the region on the importance of adopting good agronomic practices (variety, palm density, irrigation, frond pruning, offshoot removal, detect hidden breeding sites etc.) in relation to RPW infestation and its management. • Generate data on the impact of agronomic in relation to RPW infestation and its management. ***Prospect*** • The importance of agricultural practices in relation to RPW infestation and its management right from planting stage appreciated and adopted by farmers/other stakeholders. • Capacities of farmers/national staff built on this aspect through national/regional initiatives.	Aldryhim and Al- Bukiri, 2003; Al-Ayedh, 2008; Sallam *et al*., 2012

New RPW-IPM Tools

In recent years, a large number of new RPW-IPM tools (detectors, surveillance drones, pesticides, palm injectors, semiochemicals, biological control agents, palm shredders, micro wave treatment devices, etc.) became available in the market. These IPM tools need proper testing and validation at the national and regional levels so that only field worthy technologies that are not costly and easy to use are made available to the farmers.

Recent FAO Initiatives Against RPW

During 2018 there have been two major FAO initiatives against RPW that have arisen mainly as an outcome of the "*Scientific Consultation and High-Level Meeting on Red Palm Weevil Management*" held in Rome during March 2017.

1. FAO Programme on Red Palm Weevil Eradication

This project aims at creating a framework for cooperation and coordination of efforts at the regional level for supporting the integrated and sustainable management programs to control RPW; and to reduce its devastating effects on the environment and food security, and socio-economic impact on rural communities.

The objective of this project, is to support efforts/programs of countries in the NENA region to contain the spread and eradication of the pest. The key outputs of the project, revolve on the governance (policies and regulations in order to support the sustainable management of RPW, including phytosanitary and quarantine management practices for fast eradication of RPW and rational use of pesticides), monitoring (early warning, and risk assessment system of RPW control), scientific research (innovation for long-term solutions), capacity building (for stakeholders, farmers, and improved access to sustainable management practices for RPW) and coordination (RPW control response coordinated across countries and the region).

The program fosters ongoing research on the applicable approaches of biological control and innovative detection and control methods. Research priorities on RPW in the project will be identified on the criteria of innovation, applicability, transferability, field experience, sustainability, simplicity/practicality and user-friendly technologies.

2. FAO Global RPW management platform

This project aims to address critical shortcomings in the field for effective monitoring and management of RPW; to systematically collect standard geo-referenced data for which FAO is developing a global RPW monitoring and early warning system. This system consists of a mobile App for data collection in the field and GIS-based online system for data analysis and mapping combined with remote sensing imagery.

In conclusion it can be said that to take RPW control to new level, there is an urgent need to address the gaps and challenges of each of the RPW-IPM components, besides studying the socio-economic impacts and enhance farmer participation in the control program.

الملخص

فاليرو، جوزيه روميو، ميشيل فيري، ثائر ياسين وشوقي الدبعي. 2019. لمحة عامة حول الثغرات والتحديات وآفاق إدارة سوسة النخيل الحمراء. مجلة وقاية النبات العربية، 37 (2): 170-177.

برزت سوسة النخيل الحمراء *Rhynchophorus ferrugineus* Olivier كآفة رئيسة لأشجار النخيل في النظم البيئية الزراعية المتنوعة حول العالم. اتخذت سوسة النخيل الحمراء من جنوب وجنوب شرق آسيا موطناً حيث كانت آفةً رئيسةً لنخيل جوز الهند؛ ومنذ ذلك الحين فقد سجلت على نخيل التمر في منطقة الشرق الأوسط في منتصف الثمانينات من القرن الماضي، وانتشرت سريعاً وبشكل رئيسي من خلال تداول المادة النباتية المصابة. كما تشير التقارير الأخيرة التي تتبع غزو هذه الآفة أنّها قد وجدت لها موطئ قدم في منطقة القوقاز حيث تمّ اكتشاف نشاطها في كلّ من سوتشي في روسيا وأبخازيا في جمهورية جورجيا وكذلك في شاطئ كوبوليتي. ومن بين التقنيات الأخرى فقد طبقت برامج المكافحة المتكاملة لسوسة النخيل الحمراء باستخدام المصائد الفرمونية/الطعوم الغذائية ولكنّها لاقت نجاحاً محدوداً. إنّ الثغرات والتحديات الرئيسة التي تواجه تطبيق برامج الإدارة المتكاملة ضمن أطر هذه الاستراتيجية تتمثل في صعوبة الكشف المبكر للآفة، تطوير وتبني لوائح الصحة النباتية، عدم مشاركة المزارعين في هذه البرامج وندرة البيانات المتعلقة بتقييم الجدوى الاجتماعية-الاقتصادية كانت من بين عدّة عوامل أخرى ساهمت في جعل السيطرة على سوسة النخيل الحمراء واستئصالها عمليةً معقدةً وعالية الكلفة. في الجانب الإيجابي فقد تمّ استئصال هذه الآفة في جزر الكناري ويوشك القضاء عليها في موريتانيا؛ كما تمّ تجنّب انتشارها على نطاق واسع في واحات النخيل في كلّ من عمان والأردن، حيث تبيّن أنّ مدخلات جيدة للإدارة طُبّقت بدقة وحققت هذا النجاح. وخلال الاجتماع العلمي رفيع المستوى والذي عقد خلال شهر آذار/مارس من عام 2017 حول إدارة سوسة النخيل الحمراء فقد دعت منظمة الأغذية والزراعة التابعة للأمم المتحدة إلى وجود حاجة ملحّة لتطوير استراتيجية لسوسة النخيل الحمراء تضافر الجهود والموارد على المستويات القطرية والإقليمية والعالمية لاحتواء انتشار هذه الآفة المدمّرة. وصياغة الاستراتيجية الطارئة لاحتواء سوسة النخيل الحمراء والتي تهدف إلى دعم جهود/برامج البلدان لكبح انتشار الآفة وتجنيب خوض مواسم في فوضى التفشي الهائل. وقد نتج عن ذلك "برنامج منظمة الفاو حول تفشي سوسة النخيل الحمراء في منطقة الشرق الأدنى وشمال إفريقيا" لإحكام السيطرة وتحديث: المراقبة/الرصد، البحث العلمي، بناء القدرات والتدريب. ويرعى البرنامج أبحاث جارية بشأن المقاربات التطبيقية للمكافحة الحيوية والطرائق المبتكرة للكشف المبكر عن الآفة ومكافحتها. وعلاوة على ذلك فإنّ "خطة منظمة الأغذية والزراعة العالمية لإدارة سوسة النخيل الحمراء" تهدف بشكل رئيسي إلى ربط الآفة باستخدام تطبيقات الهاتف المحمول والتقنيات المعتمدة على نظم المعلومات الجغرافية. وسيسلط هذا العرض الضوء على الثغرات والتحديات الكامنة في الاستراتيجية الحالية للمكافحة المتكاملة لسوسة النخيل الحمراء مع آفاق تطوير كلّ عنصر من عناصر هذه الاستراتيجية؛ وذلك استناداً إلى معرفتي الواسعة حول الحالة الاجتماعية-الاقتصادية ومشاركة المزارعين وغيرهم من أصحاب المصلحة.

كلمات مفتاحية: *Rhynchophorus ferrugineus*، نطاق الإدارة، إقليمي، عالمي، قيود، رؤية.

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Red palm weevil (*Rhynchophorus ferrugineus* Olivier): Recent advances

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Abstract

Gonzalez, F., S. Kharrat, C. Rodríguez, C. Calvo and A.C. Oehlschlager. 2019. Red palm weevil (*Rhynchophorus ferrugineus* Olivier): Recent advances. Arab Journal of Plant Protection, 37(2): 178-187.

Red palm weevil (RPW, *Rhynchophorus ferrugineus*) is the most important pest of date and Canary palm in the Middle East, Europe and North Africa. An important management technique has been trapping using the male produced aggregation pheromone, a palm produced kairomone (usually ethyl acetate) and food. The latter needs replacement every 2-4 weeks to maintain good attraction to traps. The use of low service or serviceless traps is viewed by many as the next step in the evolution of the mass trapping technique. Recently a trap sold as the Electrap™, has been introduced to the market as a dry, serviceless trap. Its alleged mechanism of action is based on the attraction of insects via electromagnetic radiation. According to the manufacturer, light emitted into the trap is focused into a resonance chamber containing pheromone and kairomone and from this chamber specific frequencies of electromagnetic radiation are emitted which contact the insect and result in its attraction to the trap. Generation of the attractive electromagnetic radiation is supposed to be due to mirrors on the internal sides of the chamber containing the pheromone and kairomone. In this study, we have examined the Electrap™ with and without mirrors in the chamber and compared the effectiveness of the Electrap™ vs the standard and modified bucket traps using *R. palmarum* as a surrogate organism. Our findings indicated that mirrors are not necessary for attraction of *R. palmarum* to the Electrap™ and that "serviceless" bucket traps are equally attractive. We also determined that the performance of the Electrap™ is due to retention of captured palm weevils by the bristle ring inside the conical entry point. Modification of side entry bucket traps by substitution of side entry by a conical entry point on the top results in better weevil retention. Top cone entry bucket traps retain water 3X better than side entry bucket traps. Additionally, we also present data for an "attract and kill" formulation tested against RPW in Malaysian coconut. The attract and kill formulation reduced monitoring trap captures in the test site by over 95% from pre-application and is effective for at least 9 months. Both cases represent new insights and research avenues to develop better control of palm weevils.

Keywords: Conical traps, Electrap™, mass trapping, pheromones, serviceless traps, attract and kill.

Introduction

Coconut, oil, date and canary palms are of economic and cultural importance (Barlow *et al*., 2003; Chao and Krueger, 2007; Debmandal and Mandal, 2011). In the last century cultivation of these palms has become increasingly challenging due to the large areas devoted to their monoculture. Currently, there are roughly 1 M hectares of date palm, around 14 M hectares of coconut palm and 21 M hectares of oil palm worldwide (FAOSTAT, 2018). These crops share weevils of the family Rhynchophoridae as common threat. Palm weevils are currently ranked as the most devastating insect pests to palms. This is due to the ability of larvae of this weevil family to develop and cause damage inside palm stem tissue (El-Juhany, 2010; Giblin-Davis *et al*., 1996; Milosavljevic *et al*., 2018). Among these weevils, the red palm weevil *Rhynchophorus ferrugineus* Oliver (RPW) and the American palm weevil *R. palmarum* Linnaeus are the most serious threats to date and oil palm, respectively (Faleiro, 2006; Rochat *et al*., 1991). In addition to direct larval damage *R. palmarum* vectors the nematode responsible for the red ring disease (Gerber and Giblin-Davis, 1990).

Before the mid 1990's management of these pests was based on insecticide spraying and injection often coupled with cutting of infested palms (Abozuhairah *et al*., 1996; Oehlschlager, 2006; Rodríguez *et al*., 2016). In the last two decades mass trapping using traps baited with male-produced pheromones in combination with food baits has evolved as a major component of most area-wide weevil management programs (Faleiro, 2006; Faleiro *et al*., 2011; Giblin-Davis *et al*., 1996; Oehlschlager, 2006; Rodríguez *et al*., 2016). In the Americas, side entry bucket traps with male-produced pheromone of *R. palmarum* and insecticide-treated sugarcane led to successful management of *R. palmarum* populations in Central America, leading to decreases of the vectored red ring disease of over 80% in 1 year in Costa Rica and 94% in Honduras over 5 years (Oehlschlager *et al.,* 1993, 2002; Rodríguez *et al*., 2016). These reductions were achieved in oil palm at very low trap densities that averaged 1 trap / 5 hectares (Rodríguez *et al*., 2016). The most effective trap for *R. palmarum* consists of a bucket trap with side entry containing a pheromone lure, fermenting food baits, the kairomone ethyl acetate (Chinchilla *et al*., 1995; Rodríguez *et al*., 2016), and sufficient insecticide to immobilize arriving weevils.

For *R. ferrugineus,* chemical analysis of male produced pheromone determined 4-methyl-5-nonanol (ferrugineol) as the aggregation pheromone of this species (Dembilio and Jaques, 2015; Hallet *et al.,* 1993). Abozuhairah *et al.* (1996) showed increased attraction when combined with the minor pheromone component 4-methyl-5-nonanone at a ratio of 9:1. Further studies also determined higher captures when the pheromone is combined with food baits, especially fodder dates placed on black bucket traps (Abuaglala and Al-Deeb, 2012). Furthermore, research carried out in the United

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Arabic Emirates (UAE) in 1997 and in Egypt in the same year demonstrated increased captures of 2.6X and 5X respectively, to traps baited with ethyl acetate in combination with the major and minor pheromone components of *R. ferrugineus* (Oehlschlager, 2006). It has also been determined that 1 to 10 traps per hectare are suitable for control of low and high infestations, respectively (Faleiro *et al*., 2011). A large study carried out in 10 commercial farms of the UAE demonstrated significant reductions of infested palm trees (ranging from 90.4 to 100%) by using bucket traps with the pheromone ferrugineol and fodder dates as food bait (Kaakeh *et al*., 2001). Since then, the use this system has become a fundamental component of an integrated pest management strategy to control this pest, responsible for population reduction of up to 52% in date palms of the UAE (Abbas *et al*., 2006; Faleiro *et al.,* 2011).

Despite the success of pheromone and food-based systems to mass trap weevils, their use has several practical constraints. For instance, food baits need to be replaced every 2-3 weeks (Fiaboe *et al*., 2011; Hallet *et al*., 1999). High temperatures cause water evaporation and hence, unless an insecticide is used, captured insects are not quickly killed and escape (Oehlschlager, 2006; Vacas *et al.,* 2013). Servicing of traps has been the primary constraint in area-wide mass trapping programs. A suggested alternative is the use of paste matrix formulations that release pheromone and contain contact insecticides capable of attracting and killing weevils (A&K). Although promising results have been observed in Saudi Arabia (El-Shafie *et al*., 2011) and India (Gonzalez, 2018), this technology relies on pesticide, which most countries prefer not to use. After 7 years of trials there is no widespread use of the A&K technique in palm and no registered commercial product.

Since mass trapping is conducted in the Americas against *R. palmarum* in oil palm, and these traps contain insecticide, escape is minimal (Oehlschlager, 2006; Rodríguez *et al*., 2016). In the Middle East and North Africa and Europe trapping for *R. ferrugineus* usually involves trapping without insecticide in which case escape from traps is expected to be higher. Recently, attention has turned to improvement of trap design to improve the efficiency of trapping programs. The goal is to develop a trap bait that does not need replacement and a trap that decreases escape (Al-Saroj *et al*., 2017). The first serviceless trap, the Electrap™ (UAE FIRST, Abu Dhabi, UAE) was recently introduced into the commercial market in the Middle East (Porcella, 2013). This trap is claimed to function by allowing sunlight to enter the trap and penetrate an internal radiation chamber whose interior sides are covered in mirrors and into which pheromone and ethyl acetate are evaporated. According to the manufacturer vibrational radiation is emitted from the chamber which then is detected by the insect that is, in turn, attracted to the source of the radiation within the trap (Al-Saroj *et al.*, 2017; Burr, 2002). Although the vibrational radiation theory has been disproven by overwhelming evidence of molecular interaction in insect olfaction (Antony *et al,* 2016, 2018; Block *et al*., 2015; Vosshall, 2015), Electrap™ was equivalent in capture to the standard side entry bucket trap used in area-wide Saudi Arabia for mass trapping *R. ferrugineus* and to a pheromone, kairomone and food baited Picusan™ trap (Al-Saroj *et al.*, 2017; Dhouibi *et al.,* 2017).

Since *R. palmarum* has been a good surrogate for *R. ferrugineus* in development of mass trapping techniques, and considering the contradicting alleged mechanism of the Electrap™ we sought to understand the ability of the Electrap™ to capture *R. ferrugineus* by studying its efficiency in capture of *R palmarum*. We compared capture of *R. palmarum* in the Electrap™ baited with Rhyncholure™ (pheromone) and ethyl acetate (kairomone) dispensers inside the radiation chamber but where one set of Electraps™ contained mirrors and a second set that did not contain mirrors in the radiation chamber. The pheromone and kairomone dispensers were of the same size as those used in the Electrap during 2016 and 2017 and did not obstruct mirrors as per manufacturer's guidelines. We compared captures of *R. palmarum* obtained with these traps with those obtained using identical dispensers in a standard bucket trap modified for top cone entry. In a separate experiment, we compared the effectiveness of Electraps™ in which Rhyncholure™ and ethyl acetate dispensers were placed in the radiation chamber vs outside the radiation chamber. We further compared the dry Electrap™ baited with Rhyncholure™ and ethyl acetate dispensers to the standard bucket trap baited with food, the same pheromone and kairomone used for capture of *R. palmarum* and a bucket trap modified for top entry only also baited with food and the same pheromone and kairomone. We also compared the efficiency of the Electrap™ with and without the bristle ring at the top to determine how this feature affects retention efficiency. We further conducted experiments on retention of *R. palmarum* and water in standard bucket traps and bucket traps modified for top entry.

In an A&K trial in Malaysian coconut, we tested Smart Ferrolure+ (Semiochemical Matrix Advanced Release Technology) paste for the control of *R. ferrugineus* in a coconut plantation.

Materials and Methods

Study sites

All experiments relating to trapping of *R. palmarum* were conducted within a 17,000 ha commercial oil palm plantation in Coto, in South Eastern Costa Rica. For each experiment, pre-evaluation determined the presence of *R. palmarum*. Normal practices of pruning, harvesting and phytosanitation were continued during the study. Per normal practice no insecticides were applied to control the weevils.

In the A&K experiment, an experimental coconut palm plantation of 4 hectares located in the University of Kuala Perlis, Malaysia was used. Normal practices of pruning, harvesting and phytosanitation were continued during the study, and no insecticides were applied to control the weevils.

Trapping experiments

Standard bucket traps were 10 liter plastic buckets with four side entrances buried to the level of the entrance ports (Oehlschlager *et al.*, 2002). Each trap contained 7 sugarcane halved sticks (20 cm) dipped in 0.1% Benfuracarb, a slow release dispenser containing the pheromone rhynchopherol (Rhyncolure,™ approx. 7 mg/day, ChemTica Int., Costa Rica) and a slow release dispenser emitting ethyl acetate (20-40 mg/day, ChemTica Int., Costa Rica) hung from the inside of the lid (Figure 1A). Electraps™ were baited with the same rhynchopherol and ethyl acetate lures that fit into the radiation chamber and obstructed no more than 4 cm^2 of the side mirrors of the chamber. These dispensers were the same size and shape as the Ferrolure+ and ethyl acetate dispensers used in the Electraps™ when they were evaluated in Saudi Arabia for comparison against standard traps used in Saudi Arabian mass trapping programs against *R. ferrugineus* (Al-Saroj *et al*., 2017). Both sets of lures were designed to function according to trap manufacturer's specifications inside the radiation chamber by obstructing as little of the mirrored surface as possible while providing efficacious release of the semiochemicals. A bucket trap was modified to contain the cone and disk portion of a Unitrap fit into an entrance hole in the center of the lid (Figure 1B). The cone was modified to have a bottom entry diameter of 5.5 cm and cut on the perimeter so that the rim rose no more than 0.5 cm above the lid surface. The first of these modifications was made so that the entry diameter would be close to that of the Electrap™ while the second modification was to allow a low vertical barrier to entering weevils. Modified bucket traps were always buried to lid level to allow weevils to crawl into the trap. Standard bucket traps were always buried to the level of the side entry ports so that weevils that landed near the trap could easily crawl in. Electraps™ (Figure 1C). were used unmodified according to manufacturer's directions as well as at variance with the manufacturer's directions with pheromone and kairomone lures placed outside the radiation chamber, with mirrors removed and with bristle ring removed. Experiments were set up in a complete randomized block design with 50 meters between traps within a replicate and between replicates. Insects were counted and removed weekly and for multi-week experiments trap positions were re-randomized weekly. Retention of *R. palmarum* by the bristle rings at the top of the Electrap™ as well as retention experiments of the standard bucket trap and the bucket trap modified for top entry by addition of a Unitrap cone and disk to the lid of the bucket trap were determined by placing 10 freshly captured *R. palmarum* of mixed sex in a trap which was within a 2 M X 2 M X 2 m wire cage (outside in shade) and observing the proportion of *R. palmarum* that remained in a trap after 24 hrs. Similarly, we observed the changed in water content by weighting 1 L of water in standard bucket traps vs the modified lid traps at the beginning of the experiment and 24 hours later.

Attract and kill experiment

The experimental plot was a RPW infested 4 ha coconut planting in the field station of the University of Malaysia at Kuala Perlis, Malaysia containing 446 palms. Three weeks prior to the placement of A&K formulation four bucket traps with pheromone (Ferrolure), kairomone (ethyl acetate), 4-6 sticks of 20 cm long sugarcane partially immersed in soapy water (1% laundry detergent) were distributed on the four sides of the 4 ha plot of RPW infested coconut (1 trap/hectare), and the populations were recorded weekly. Sugarcane was replaced every 2 weeks. The A&K matrix consisted of an emulsified wax formulation of Ferrolure in combination with cypermethrin (5%, Smart Ferrolure™). A&K paste was applied during the late afternoon, to all palms in the plot at the rate of 2 dollops (of 3 g each) per tree on the North and South side of the stem of the palm at a height of ~ 2 meters, using a standard caulking gun modified to dispense the required quantity. This procedure was repeated 3 months after the first application. No application was performed elsewhere (traps or non-hosts). Monitoring traps were checked bi-weekly during 12 months after application.

Statistical Analyses

In the case of trapping tests, normality tests were carried out for each set of data. For all trials, pairwise comparisons were performed with Student T-Test. Test with multiple treatments were also analyzed with repeated measures ANOVA and LSD as posthoc. In case of not normally distributed data, we used Kruskall Wallis Test and the Dwass, Steel, Critchlow-Fligner Method for pairwise comparisons. In the case of the A&K experiment a time series exploration analysis with an augmented Dickey-Fueller Test was performed to observe the trend in the plot receiving the A&K application. A Wilcoxon Two Sample Test was also used to compare the average captures pre- and post- A&K application. All analyses were carried out with SAS Studio 9.4 (SAS Inc., NC, USA).

Figure 1. Different trap designs compared for mass trapping of weevils: (A) standard bucket trap with lateral entrances, (B) Electrap ™ and (C) modified standard bucket trap with single cone entry point on lid.

Results

Trapping experiments

A comparison of Electraps™ baited with Rhyncholure™ (pheromone) and ethyl acetate (kairomone) with and without mirrors in the radiation chamber revealed that Electraps™ with mirrors and those without mirrors functioned equally (Figure 2). This experiment also revealed significantly greater capture for a bucket trap modified for top cone entry baited additionally with sugarcane (Figure 2).

Comparison of Electraps™ in which Rhyncholure™ and ethyl acetate dispensers were placed inside the mirrored radiation chamber and outside the radiation chamber revealed that there is a benefit to placement of the dispensers in the chamber. When the dispensers are inside the chamber statistically more *R. palmarum* are captured than when the dispensers are placed outside the chamber (Figure 3).

Comparison of the standard side entry bucket trap with a bucket trap modified for top cone entry by addition of a Unitrap cone and disk revealed that the later performed significantly better than the standard bucket trap when baited with Rhyncholure™, ethyl acetate and sugarcane (Figure 4).

When sugarcane is omitted from the bait in the modified bucket trap it captured significantly less *R. palmarum* than either the standard bucket trap or the modified bucket trap containing sugarcane (Figure 4).

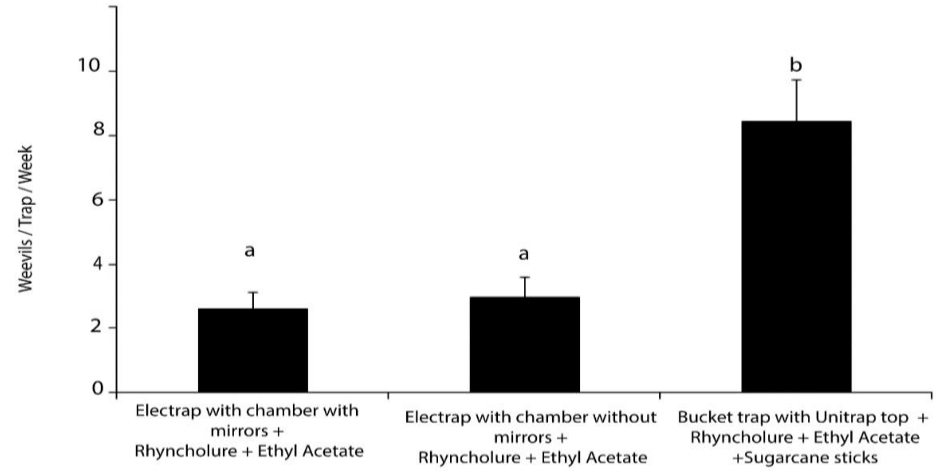


Figure 2. Average weekly captures of *R. palmarum* in Electrap™ with and without mirrors in internal emission chambers and bucket trap with Unitrap top with sugarcane. Experiment conducted in Palma Tica experimental farm, Coto 47, Costa Rica, July 11 to September 5, 2017. Insects counted, removed and trap positions re-randomized weekly. Statistically equivalent captures week to week throughout experimental period. Bars topped by different letters are statistically different by student T-test, $p < 0.05$, n = 23 and repeated measures ANOVA with LSD $p < 0.05$, n = 3..$p < 0.05$, n = 3.

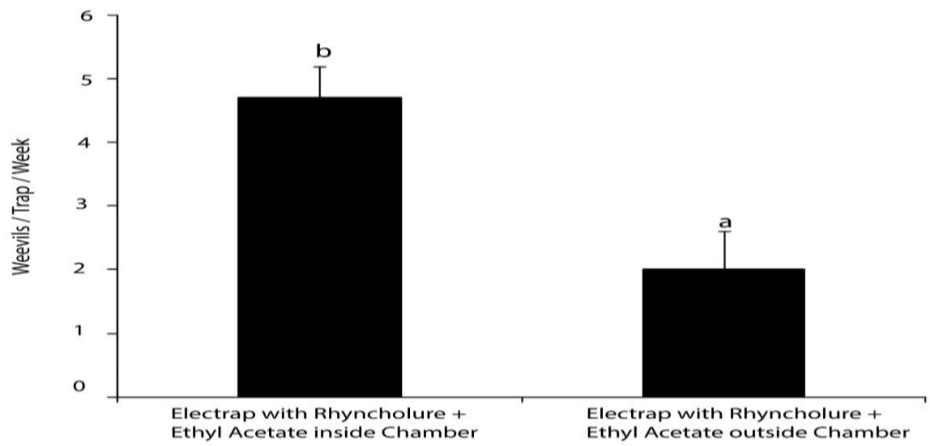


Figure 3. Average weekly capture of *R. palmarum* in Electraps™ in which Rhyncholure and ethyl acetate dispensers were placed inside or outside mirrored radiation chambers. Experiment conducted in Palma Tica experimental farm, Coto 47, Costa Rica, July 11 to August 11, 2017. Insects counted, removed and trap positions re-randomized weekly. Statistically equivalent captures week to week throughout experimental period. Bars topped by different letters are statistically different by student T-test, $p < 0.05$, n = 10.

Retention experiments revealed that the presence of the bristle ring at the top of the Electrap™ resulted in an almost complete retention of *R. palmarum* within the trap over a 24 hour period while when the bristle ring was removed the number of escapees increased by ~3X over the same time period. The traditional side entry bucket trap, was the trap type that allowed the highest number of weevils to escape, whereas the bucket trap modified for top cone entry was the best bucket trap for retaining *R. palmarum* (Figure 5). Water retention is also better in the bucket trap with Unitrap top. Over 24 hours the standard bucket losses up to 3 times more water than the modified bucket trap with Unitrap top (Figure 6).

Attract and kill experiments

During the first week of evaluation (prior A&K treatment of palms) the average number of weevils captured per trap was 13.25. During the subsequent 2 weeks the average per trap decreased at a rate of approximately 2.75 less individuals per week. However, after the A&K application RPW captures dropped from 7.75 to 1 in one week and followed a trend close to zero in the following weeks. During the next months from the first application RPW captures averaged 0.15 weevils per trap per week (Figure 7A). As expected, the comparison of captures pre- and post-application of A&K showed a significant effect (Figure 7B).

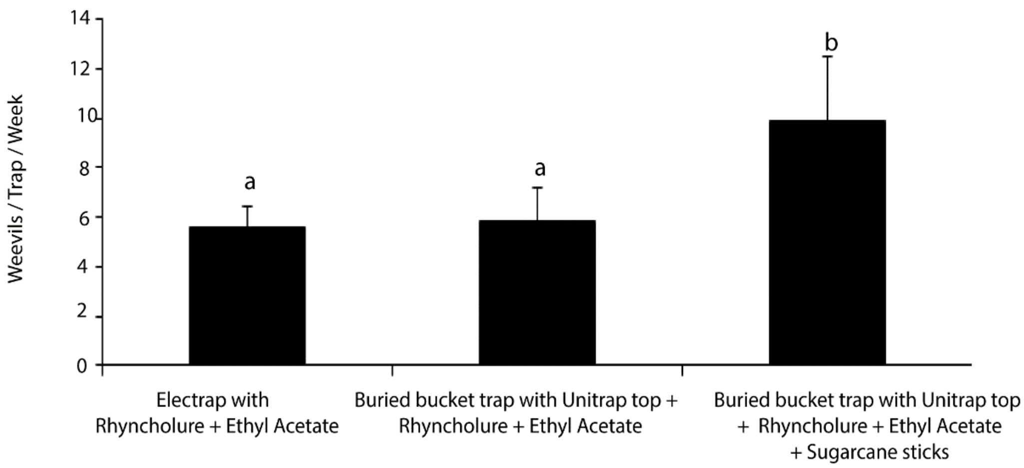


Figure 4. Capture or *R. palmarum* in different commercial traps, Electrap™, standard bucket trap with Unitrap top and standard bucket trap with sugarcane. Different letters above bars indicate captures significantly different by student T-test, $p < 0.05$, n = 7 and repeated measures ANOVA with LSD, $p < 0.05$, n = 3. Test conducted in Palma Tica experimental farm Coto 47, Costa Rica, June 14-30, 2017.

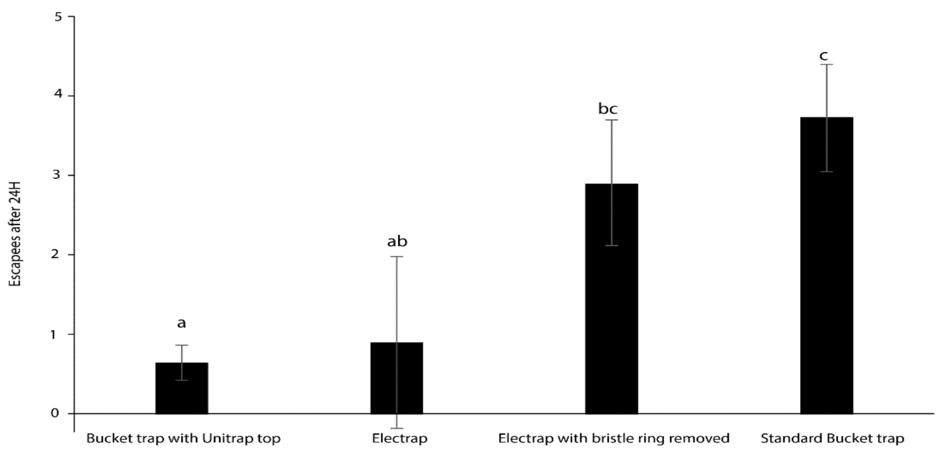


Figure 5. Average number of 10 *R. palmarum* escaping from different traps over 24 hr: Standard side entry bucket traps, Bucket traps with Unitrap top, Electrap™ and Electrap™ with bristle ring removed. Different letters above bars indicate significant differences between treatments analyzed by Kruskall-Wallis Test and contrasted by Dwass, Steel, Critchlow-Fligner Method, $p < 0.05$, n =10.

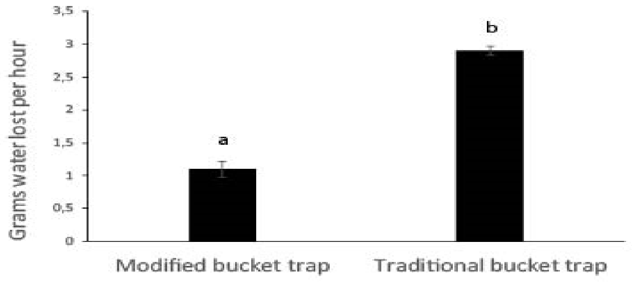
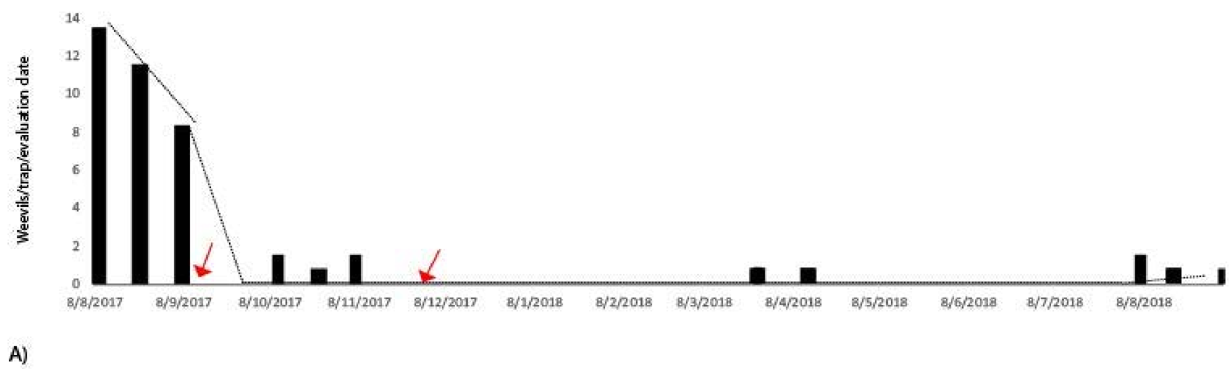


Figure 6. Average losses of grams of water per hour. Different letters above bars indicate significant differences between treatments analyzed by T-test, $p < 0.05$, n = 8.

Discussion

The advertised mechanism of action of the Electraps™ is that semiochemicals such as Rhyncholure™ and ethyl acetate are energized by natural light to vibrate and that these vibrational frequencies are detected by insect antennae (Porcella, 2013). This theory was recognized during the 1960s and 1970s among some scientists. For instance, Callahan (1975) proposed that antennae act as resonators that detect wavelengths of infrared radiation of excited semiochemicals. Merely two years later, this theory was shown to conflict with basic physics (Diesendorf, 1977). In 2015, the radiation theory of olfaction was finally put to the rest when Block *et al*., (2015) showed that independent of the vibrational frequencies of molecules they are equally detected by odorant receptors as predicted by the Nobel Prize laureates (Buck and Axel, 1991). In the intervening half century since the proposal of the radiation theory of olfaction the basis for detection of odorants by insect antennae has been clearly established to be by molecular interaction (Andersson *et al.,* 2015; Fleischer *et al.,* 2017; Szyszka and Galizia, 2015; Voshall, 2015). Indeed, the very procedure of identification of pheromones such as 4-methyl-5-nonanol, the pheromone of *R. ferrugineus,* involves electroantennal detection in which the antennae are exposed to the effluent of a gas chromatograph and exhibit a specific response to the effluent when the pheromone is eluted. Recently, Antony *et al*. (2016, 2018) provided clear genetic evidence for the molecular basis of detection of the pheromone of *R. ferrugineus* by its antennae. As our first experiment showed (Figure 2), the present results provide field evidence that the mirrors in the "Internal Emission Chamber" may be removed without impairing the functioning of the Electrap.™.



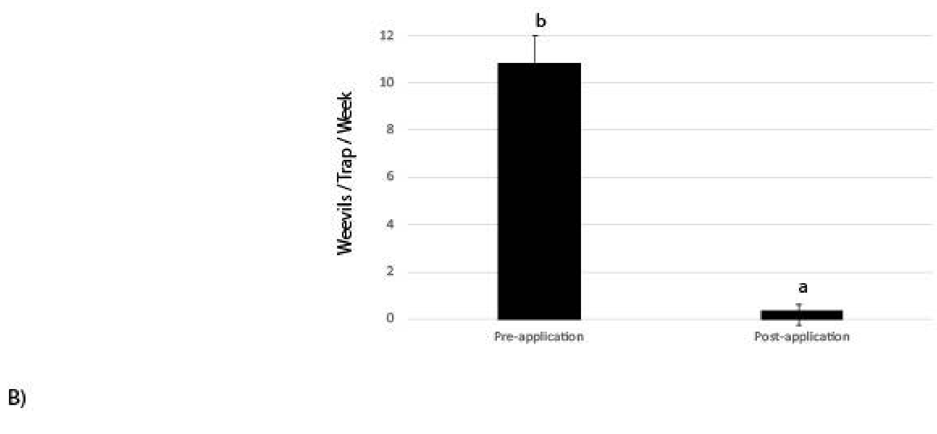


Figure 7. RPW captures in 4 traps placed on the edges of 4 ha of coconut palm in which Smart Ferrolure was applied. (A) Average captures per week per trap: arrows indicated dates at which Smart Ferrolure^{TM} was applied. Grey dotted line indicates trend. Time series analysis revealed stationary trend close to zero during the whole duration of the experiment (Augmented Dickey-Fuller Unit Root tests, $p < 0.001$). (B) Comparison of average captures per trap prior and after A&K application (Wilcoxon Two Sample Test, $p < 0.05$).

In combination with the results shown in Figure 2 we interpret the results in Figure 3 as being due to more restricted emission of semiochemical vapors from the chamber than from the trap resulting in a more constant release. This might be expected to result in higher capture due to higher release of attractants in the morning hours when a higher proportion of *R. palmarum* flight occurs. The reasoning is that as the trap warms in the morning hours the vapors already in the radiation chamber are released in higher amounts than vapors from the dispensers outside the chamber. Therefore, our results indicate that the chamber in the Electrap™ may contribute better captures, but as demonstrated, not because of the mirrors.

Since traps that have cone entry such as the Electrap™ appear to work well in retaining arriving *R. palmarum,* we examined a modification of the standard bucket trap in which the side entry ports were not present and the lid was fitted with a cone entry port constructed from a cone and disk from a standard Unitrap (Figure 4). This result is expected based on repetitive demonstration that addition of food baits increases weevil attraction (Haris *et al*., 2014; Jaffé *et al*., 1993; Kaakeh *et al*., 2001; Oehlschlager *et al*., 1993; Rochat *et al*., 2000)

An additional advantage of the modified bucket trap with Unitrap top is in its ability to retain *R. palmarum*. Within 24 hours almost 40% of *R. palmarum* in standard side entry bucket traps containing sugarcane escaped (Figure 5). By comparison *R. palmarum* are almost completely retained over 24 hours in modified top cone entry bucket traps. Retention experiments also revealed that the presence of the bristle ring at the top of the Electrap™ resulted in an almost complete retention of *R. palmarum* within the trap over a 24-hour period. When the bristle ring was removed around 30% escaped over the same time period (Figure 5). Thus, the bristle ring is responsible for substantially increasing retention of *R. palmarum* in the trap and may explain why this trap shows captures equivalent to the standard Saudi Arabian side entry bucket trap for *R. ferrugineus* (Al-Saroj *et al*., 2017). In addition, the modified bucket retains much water and therefore will require less servicing than the standard bucket trap with side entry (Figure 6).

When it comes to the application of A&K paste for the control of RPW in a coconut plantation in Malaysia, it is clear that the A&K matrix had a fast knock down effect on the population (Figure 7). This effect lasted for a whole year, even when the application was performed only twice during the initial three months.

Conclusions

Palm weevils can be controlled with mass trapping techniques that combine pheromones and kairomones. However, the costs involved in servicing significantly increase costs of this technique for area-wide use. Serviceless traps are an attractive option. The first serviceless trap to be marketed, the Electrap™, appears to function on the same principle as most other insect traps. That is, by emitting attractive vapors that are detected by the target insect and induce the latter to approach and enter the trap. Since mirrors are not necessary for functioning of the Electrap™ but placement of lures in the resonance chamber leads to increased capture it would be good to investigate large long-lived lures in the Electrap™ to determine how long efficient capture can be achieved. The lower capture in serviceless traps compared to bucket traps containing pheromone, kairomone and food could be compensated by using increased numbers of serviceless traps. Modification of bucket traps for top cone entry provides an inexpensive alternative to both Picusan™ and Electrap™ designs which both cost more than $10 USD.

Attract and kill technology appears to be a good option for rapid knockdown of RPW populations. The extended period of very low captures in monitoring traps surrounding the plot in which A&K was applied indicate that both attraction and killing is occurring nearly a year after application. Since A&K is more expensive to apply than setting traps the longevity of formulations is important.

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الملخص

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تعدّ سوسة النخيل الحمراء (*Rhynchophorus ferrugineus* Olivier) (RPW) أهمّ الآفات التي تصيب نخيل التّمر والكناري في منطقة الشرق الأوسط وأوروبا وشمال أفريقيا. تمّ اعتماد الاصطياد الكثيف كأداة مهمة لإدارة الآفة باستخدام الفيرومون التجميعي الذي يفرزه الذكور، كيرمون ينتج من النخيل (عادةً خلّات الإيثيل)، والطعوم الغذائية وتحتاج الأخيرة إلى الاستبدال كل 2-4 أسابيع للمحافظة على كفاءة المصائد في جذب الحشرات. نظراً للتكاليف الكثيرة المترتبة على المصائد التقليدية (التي تتطلّب صيانة دورية)، تعتبر المصائد التي لا تتطلب صيانة الخطوة التالية في تطوير تقنية الاصطياد الكثيف للآفة. تم مؤخراً تسويق مصيدة لا تحتاج إلى صيانة Electrap™ والتي يجري تسويقها كمصيدة ذات كفاءة عالية لا تتطلب صيانة؛ تستند آلية عملها المزعومة على جذب الحشرات بواسطة الإشعاع الكهرومغناطيسي وفق الحُزَم التي تتركّز الضوء المنتشر في المصيدة ضمن حجرة رنين تحتوي على الفيرمون والكيرمون، ومن ثم تحرير الطاقة كإشعاع كهرومغناطيسي بترددات متخصصة والتي تلتقطها الحشرة مما يسبّب جذبها للمصيدة؛ وقد تمّ الافتراض أنّ

تولد إشعاع كهرومغناطيسي جاذب يعزى إلى وجود مربي في الجوانب الداخلية للحجرة التي تحوي على الفيرمون والكيرمون قد أضاف انتشار
كفاءة مصيدة إلكتراب™ مع و دون وجود مربي في الحجرة، كما أجرينا مقارنة لكفاءة مصيدة إلكتراب™ مع مصائد الجردل (السطل) التقليدية
والمعلقة باستخدام سوسة النخيل الساحلية (الأمريكية) *R. palmarum*. كشفت النتائج أنّ وجود المربي غير ضروري لجذب *R. palmarum* إلى
مصيدة إلكتراب™، وأنّ مصائد الجردل التي تم تجهيزها بالطعوم الكيرمونية والفيرمونية أكثر فعالية في جذب الحشرة. وقد أمكن تحديد أنّ أداء مصيدة إلكتراب™ يعزى
إلى الحفاظ على حشرات سوسة النخيل الملتقطة بواسطة المصيدة في حجرة الحشرات الموجودة داخل فتحة الدخول المخروطية. وقد تبيّن أنّ مصائد الجردل
ذات المدخل الجانبي المعدلة ذات المدخل المخروطي الشكل تم وضعها أعلى المصيدة تحقق نتائج أفضل للاحتفاظ بالحشرات داخل السطل
كما أن مصائد الجردل ذات المدخل المخروطي التي تحتفظ بالماء على نحوٍ أفضل بثلاثة أضعاف مما هو عليه الحال في تلك المصائد ذات المدخل
الجانبي. فوق ذلك، قدّم أيضاً دليلاً على أن مصائد الجردل التي تحتوي على طعوم جاذبة والتي تعتمد على الجذب والقتل تعتبر مزيج فعّال لسوسة النخيل
الحمراء. وقد حققت المصائد التي تحتوي على الجاذب الحيوي في موقع الانتشار ما يزيد عن 95% مما كان عليه في تحقيق هذه
المعالجة، والتي استمرت فاعليتها لما لا يقل عن 9 أشهر، قدمت الحالي نتائج جيدة ومحاور لتطوير مكافحة أفضل لحشرات سوسة النخيل

كلمات مفتاحية: مصائد مخروطية، إلكتراب™، المصائد الغذائية، فيرمونات، المصائد الأليفة، الجذب والقتل

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An effective strategy to obtain very rapidly the red palm weevil decline in an area planted with ornamental palms

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Abstract

Ferry, M., R. Cousin, D. Chabernaud and F. Ferrero. 2019. An effective strategy to obtain very rapidly the red palm weevil decline in an area planted with ornamental palms. Arab Journal of Plant Protection, 37(2): 188-197.

To control successfully the RPW, it is essential to implement a programme conceived and applied to obtain the pest decline as fast as possible. Such objective is easy to reach when RPW is not yet too widespread and abundant. Unfortunately, in most of the infested countries, it is not at all the case anymore. The challenge now is to propose strategies and technical solutions sociologically, economically and environmentally sustainable. In a territory of five grouped municipalities in the French Riviera, has been applied since 2016 a strategy elaborated by the Phoenix Research Station (PRS) and implemented under the supervision of the inter-municipality authority in charge of this territory (CAVEM). Although the area is heavily infested by the RPW, the objective is to demonstrate that it is possible in few years to stop the palms hecatomb and to obtain a rapid decline of the RPW ("palms" refer generally in this paper to *Phoenix canariensis* that is by far the main target and main incubator of the RPW). The main challenge, here like everywhere in the infested countries, is to get the palm owners acceptation to the proposed strategy and their collaboration. One essential point that has contributed greatly to face this challenge has been the existence of a very active association of private palms owners (Propalmes 83). To obtain the public and private palms owners collaboration it was fundamental that the proposed strategy be conceived taking into consideration the capacities and economic means of these actors. Therefore, the PRS proposed that CAVEM organize the activities to facilitate as much as possible their grouping to reduce the costs to a minimum. Among the different activities, the PRS proposed that preventive treatment based on an injection technique, because of its much lower cost and its great safety compared with other techniques, be the core of the action plan. This proposal is based on the results of a theoretical analysis presented here on the evolution of the number of new yearly infested palms. This analysis allowed establishing, with a probability of 95% for the confidence intervals, the number of new yearly infested palms based on the percentage of treated palms. The field results available for the CAVEM territory for 2016 and partially for 2017, confirm the validity of this analysis. These results showed that, if as planned, the objective of 75% of injected palms on the total number of palms is reached, the number of infested palms will decrease very quickly in 3-4 years, leading to a considerable decline of the native population of RPW and of the number and size of the infested spots, that in addition will be perfectly located. Once this result will be reached, it will become quite feasible to treat all the palms, even with biological agents, in the infested spots and so finally to eradicate the RPW. Of course, the same strategy has to be followed rapidly by the surrounding territories, otherwise such result would be vain as re-infestation will occur.

Keywords: *Rhynchophorus ferrugineus*, *Phoenix canariensis*, *Phoenix dactylifera*, IPM, injection treatment, management strategy, participative approach, cost, binomial law, rapid decline, eradication, sanitation of infestation spots.

Introduction

The red palm weevil (RPW) is a deadly pest of palms species of great economic and environmental importance, especially the date palm and the coconut. It is also a deadly pest of many ornamental palm species, especially the *Phoenix canariensis*. This specie since the end of the nineteenth century represents the dominant palm specie planted in the cities of the Mediterranean coast, where it is or used to be, at the core of the exceptional and typical landscape of these cities. Unfortunately, it is also by far, the most attractive and less resistant host of the RPW. This pest is capable to attack palms whatever the size (at the difference of the date palm) and, if no action is taken to sanitize the infested palms, it kills them inevitably and rapidly: a large palm can be killed in less than 12 months. The infested *Phoenix canariensis* constitute also an exceptional incubator for the multiplication of the RPW.

The RPW was introduced in the Mediterranean region in 1993, but it was only at the beginning of the 2000s when it has been dispersed at a large scale and very quickly because of the important legal trade of palms imported from Egypt and of the legal dispersal of palms from ornamental nurseries infested via the imported palms. Inappropriate phytosanitary regulations are at origin of the general hecatomb of *Phoenix canariensis* (Ferry and Gomez, 2013). The control of the pest on the *Phoenix canariensis* in the Mediterranean area, as well as of the date palms worldwide, has been a serious failure (Ferry and Gomez, 2008a; Ferry, in press a), in spite of the fact that the strategy and techniques to control this pest have been established 20 years ago (Abraham *et al.*, 1998; Faleiro, 2006) and they are still nearly the same that are recommended today (Ferry and Al-Dobai, in press). They are also the same that have allowed RPW eradication in some locations (Ferry *et al.*, in press).

The causes of this failure that are quite similar for the ornamental palms and date palms, are now well established (Aldobai and Ferry, in press): absence of strict regulations regarding the movements of palms or insufficient respect of these regulations; flawed governance and monitoring of the RPW control programmes from the local to the national level; serious lack of knowledge of the socio-economic constraints in order to propose suitable organization and means; lack of involvement of the first concerned stakeholders: the palms owners (Abdedaiem *et al.*, in press);

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serious misconception on some aspects of the RPW biology that have led to very costly, unnecessary, counterproductive or inefficient technical recommendations (Ferry and Aldobai, in press; Ferry, in press b).

In numerous cities, especially in the Middle East, where date palms are planted as ornamental trees, the problem of RPW does not present the same degree of seriousness as in the cities of the Mediterranean region, where the main ornamental palm is the *Phoenix canariensis*. The date palms planted for ornamental purpose are usually be of great dimensions and without offshoots, characteristics that reduce a lot the risk of infestation by the RPW (Ferry and Gomez, 2012; Ferry and Aldobai, in press).

In the cities of the Mediterranean area, as the RPW is now largely widespread and as the control of this pest is inefficient if it is not conceived on a wide area based strategy, the economic constraint is crucial. Furthermore, the exceptional patrimony represented by the *Phoenix canariensis* palms is threatened to disappear in the short term if efficient programmes to obtain the rapid decline of the RPW are not implemented very quickly.

In addition, in Morocco and in Tunisia, where the RPW is only present presently on *Phoenix canariensis* in cities in the North of the countries, the risk of an accidental transport of the pest to the oasis increases with time, especially in Tunisia where it is not rare now to find palms at the last stage of infestation (Dr. N. Nasr photo of 13/10/18). In Morocco, a new outbreak was found in Nador in 2016, whose origin is very probably the infested palms of Melilla, where contrary to Ceuta, the RPW has not been eradicated.

In Israel, where the first RPW outbreaks were perfectly eradicated between 1999 and 2002, a new outbreak on *Phoenix canariensis* in the northernmost city of the country was discovered in 2009. Unfortunately, the management of this new outbreak has followed the same model as the one adopted in Europe. Consequently, the RPW has reached the date palms plantations since 2013 (personal observation) and it is now widespread in large part of the country.

For all these cities that are now very infested, the challenge is to propose strategies and technical solutions sociologically, economically and environmentally sustainable.

In this paper is proposed a strategy that could be implemented at a large scale because it is conceived to minimize the costs and to concentrate the organizational efforts on a short period, at the end of which the RPW will be contained in few and well delimited areas, where the eradication of the remaining RPW becomes perfectly realistic. The first results of implementation of this strategy, obtained in the framework of a project initiated in 2016 by a consortium of five municipalities in South East France, are also presented.

Principles of the Strategy to Obtain a Rapid Decline of the RPW

The necessity to obtain the rapid decline of the RPW

As illustrated in Figure 1 (Ferry *et al.*, in press), it is imperative to design the programs to control the RPW with the objective to obtain its rapid decline. This decline can be easily controlled as it is directly linked to the decline of the number of new infested palms, which is useful to establish at least on a yearly basis.

The scenario nº 1 (Figure 1 left) corresponds to the situation that resulted from the control programmes in all the European countries and in most of the dates producing countries: exponential growth of the RPW population, exponential hecatomb of the palms and impossibility to contain the pest. Containment of the RPW failed in all the countries where such programmes were applied. It is useless to continue such programmes in the same conditions. If the objective remains to control the pest and to save the palms, programmes based on totally different organization, means or ways to use the available resources must be designed and implemented.

The scenario nº 2 (Figure 1 centre) has been implemented for tens of years in some places. It is now clear that the continuation of such programmes is unsustainable. It is, first, very costly to maintain for an indefinite time measures just efficient to avoid the increase of the RPW population, taking also into consideration that they will not prevent a regular hecatomb of palms. Even in countries where considerable financial resources are available, it is now planned to modify such programmes in order to obtain the rapid RPW decline and, consequently, to reduce rapidly their cost. The second reason to modify such programmes is that they are based, among other measures, on the use of chemical pesticides that, in addition of resistance development, have of course on the long term negative health and environment consequences. Thirdly, with time, the risk that the RPW escapes from the zone where these programmes are applied is very high.

The scenario nº 3 (Figure 1 right) has been successful in all the places where it has been implemented.

In conclusion, to control the RPW means to design and implement programmes whose objective is clearly to obtain the rapid decline of the pest. These programmes must be carefully monitored and quickly modified if the decline of the number of new infested palms does not occur or does not occur enough rapidly.

Regarding the means to dedicate to programmes leading to the scenario nº3, a cost/benefit analysis must be conducted. Most of the time, such analysis will demonstrate that the cost to implement such programme is incomparably lower than the cost of losing the palms.

Organizational and economic approach to optimize the means and select strategy and treatments

One of the main problems that explains the failure of the RPW control in urban environment has been the great dispersal of the efforts in time and space and the “everyman for himself” behavior. To be efficient, a programme to control the RPW must be conceived and implemented to involve all the stakeholders in an action plan adopted with their participation and supervised by a recognized authority, and associated with the control and strong institutional support of the plant protection organization.

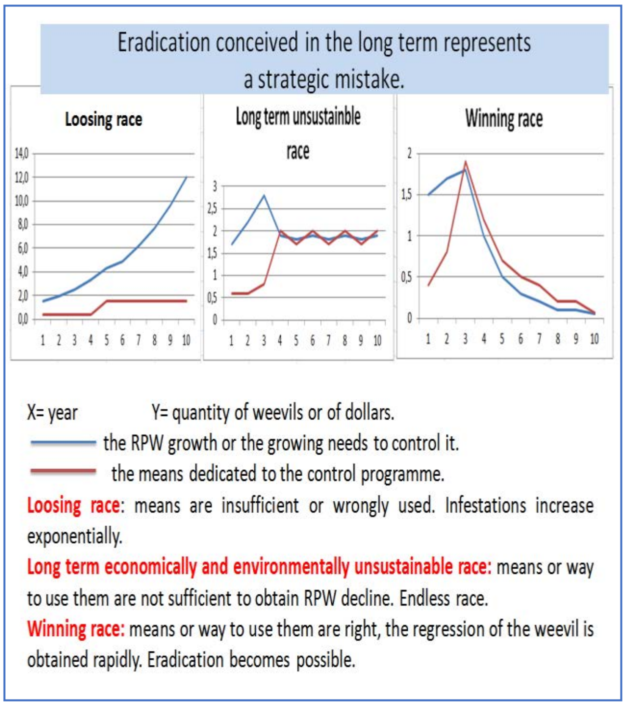

Figure 1. The 3 different scenarios to fail or to succeed the RPW control

In urban environment, the right level of management to implement such action plan is, at the local level, the municipality or, still better, the urban community that groups various municipalities that, furthermore, are very often the owners of an important part of ornamental palms. Municipalities or urban communities dispose, to varying degrees, of different institutional, human and material means that give them the capacity to implement the different tasks of the supervision function: institutional legitimacy; communication, coordination and training capacities and facilities; competence to establish and manage a GIS to manage the program; means to locate the palms owners and the palms (cadastre, orthophotos, etc.); capacity to negotiate collective and to planify the interventions with the objective to reduce as much as possible the cost of the programme for the municipality and the palms owners; capacity under the control of the Plant Protection Authority to establish and to give force to a local regulation and police to control its compliance (Mairie de Vence, 2017).

The strong commitment of the political leaders of the municipalities, with the full institutional support of the Plant Protection authority is of course an absolute prerequisite to give to the municipalities' concerned staff the means to implement the management of the RPW control programme. When this is the case, the efficiency of a municipality to manage a collective plan of action against the RPW is well demonstrated (Paz *et al.*, 2010).

The mobilization of local associations that represent the private palms owners is also essential. Finally, the local action plans must be imperatively coordinated at the regional and national level by the different authority levels in charge of this issue to make sure that it is correctly applied in the whole concerned territory.

The adoption of a collective plan of action will also allow to implement its different components in a much more efficient and less expensive way than if they were implemented in a disperse and individual way. Furthermore, the objective of such plan is to quickly obtain RPW decline. Consequently the organizational efforts as well the cost of the action plan will be as limited as possible in time. This point is very important to facilitate the acceptance of the majority of the stakeholders to contribute to its realization.

Figure 2 represents the different components of the IPM model recommended for more than 20 years to control the RPW. The arrows indicate the strong interaction between the different components (Ferry and Aldobai, in press).

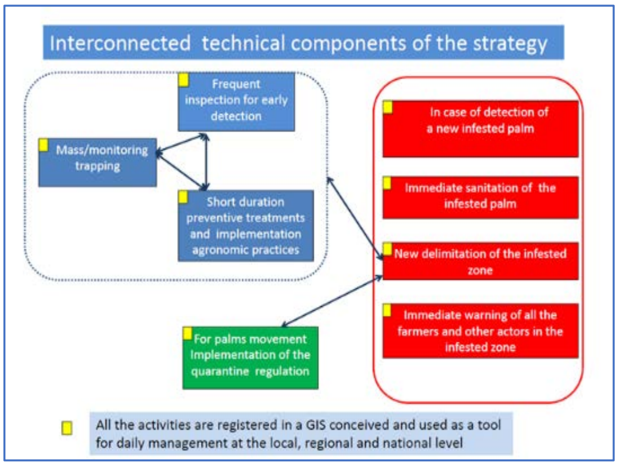

Figure 2. The area-wide integrated strategy to control the RPW.

Frequent Inspection for Early Detection of Infested Palms

This activity is essential, as the early detection of infested palms allows to eradicate them or preferably to sanitize them, and consequently, to eradicate as soon as possible all the RPW that these infested palms contain. The early detection followed immediately by the sanitation or the eradication of the infested parts of the palms allows to prevent or limit considerably the RPW multiplication as well as the infestation of the neighbouring healthy palms and the RPW spread.

In some places, the inspection task has been entrusted to public or private organizations. This solution is very costly, and when this task has to be paid by the private owners, it is likely not to be implemented at all. Consequently, frequent inspection, even when it was compulsory, has never been applied systematically and at a large scale. As for all the components of the IPM, it has rarely been considered that the main concerned stakeholders, the palms owners or their gardeners, could be efficiently involved in this task if only they were aware and trained and if, in case of detection, the only proposed solution would not have been to eradicate the infested palm (Ferry and Gomez, 2007).

As the visual symptoms of early infestation can perfectly be detected from ground and are now well characterized (Ferry and Gomez, 2012), frequent inspection can be implemented by the palms owners or their gardeners with the advantage that they are often present permanently or frequently in the place where are they palms.

The successful implementation of this task by the palms owners is linked to the efforts developed to involve them, as far as possible, in the elaboration and the implementation of the action plan.

Mass Trapping

For this component, the situation is quite similar to the one described regarding frequent inspection. Entrusting this activity when the objective of the trapping is to contribute to reduce usefully the RPW population (high density of traps) is very expensive. As the instructions for the traps are not complicated, even if they are not of the dry type, the palms owners, their gardeners or any other volunteers can easily manage them (Comune di Marsala, 2009). When possible, the registration of the captures constitutes an essential information to monitor the pest and to control the efficiency of the action plans. Unfortunately, the use in Europe of the traps, excepted for monitoring, is not authorized, as the societies producing the RPW pheromone have not implemented the procedure for its approval.

Sanitation of the Infestation Spots

In the RPW control programmes, it is very often spoken of curative treatments. This formulation is in fact not appropriate for such programmes as the main objective of these treatments is to eradicate the RPW present in the infested palms. We should speak of sanitation of the infestation spots represented by the infested palms where the RPW multiplies rapidly and from where it spreads if this sanitation is not realized rapidly.

The sanitation of the infestation spots consists of mechanical and/or chemical treatments to kill all the RPW present in the infested palm. If this operation is done in time, the infested palms can be cured, but as already say, it is not the primary objective although it is very important.

Contrary to the previous components, sanitation of the infestation spots (excepted when they are small), presently mainly based on mechanical sanitation, requires experience and equipment that generally prevent the implementation of these operations by the palms owners or their gardeners. The assistance of specialized well equipped professionals is usually necessary. The cost and the complexity of these operations can be seriously reduced once it is understood that infested parts can easily and advantageously be separated from no-infested ones and when the risk presented by the infested parts of the palm and by the wastes is well understood (Ferry and Aldobai, in press). Unfortunately, these operations have been implemented and even enforced erroneously during many years: eradication of palms that could have been sanitized, eradication of the whole infested palms when it is sufficient, easiest, far less costly and quite possible in situ to eradicate only the infested parts. Consequently, this IPM component, although compulsory and fundamental, has been little implemented by the private owners, especially when the infestation was detected late, preventing the rescue of the palms. It has been very often implemented so late that the palms were already killed with the lower crown fronds drying, that means that the palms were no more infestation spots as all the weevils had abandoned them.

By grouping these spot sanitation operations to reduce their cost, by increasing the inspections to detect the infested palms in time to prevent or to stop the RPW spread and to save as much as possible the infested palms, by implementing the other measures of the action plan to reduce considerably the risk of re-infestation, by enacting and enforcing municipality regulation, it would be possible to improve the implementation of this component, thanks especially to a better acceptation by the palms owners.

Preventive Treatments

In the RPW control programmes, the first objective of the preventive treatments should be conceived as a measure to contribute to RPW rapid decline. The protection of the palms is a consequence, just as the eradication of the infested parts of the palms can cure the infested palms if it is realized in time.

Preventive treatments must be implemented only in the framework of a plan of action conceived with the objective to reach rapidly the RPW decline, otherwise they are not sustainable either for economic reasons and/or for health and environmental reasons.

The palms to be treated are located in the zone (the infested zone) where infested palms have been detected or where weevils have been captured. From these palms will be infested new palms if not action is implemented to avoid it. To establish for sure the limits of the infested zone is impossible. They must be fixed taking into consideration the aggregative dispersal behaviour of the RPW (Faleiro *et al.*, 2002; Massoud *et al.*, 2012). Their limits correspond in fact to a compromise between the operational and financial means that can be dedicated to the measures to implement in these zones and the establishment of the largest possible safety margin.

The preventive treatments are of two types:

(1) Soaking the extreme basis of the fronds that are the target sites of oviposition and adults refuge. Unfortunately to be efficient, the treatments with chemical products or biological agents have to be repeated every 3-4 weeks, and for the tall palms require the use of lift platforms. Consequently, the cost of these treatments is very high and they are rarely applied, even in countries like France, where they are compulsory since 2010 on all the palms located in the infested area (Ministère de l’Agriculture, 2010). In addition, the application of treatments in cities either with chemical products or *Beauveria bassiana* (but not with nematodes) requires the adoption of complicated regulatory precautions.

(2) Injecting insecticides in the trunk. The problem of these types of treatments is that the plants are not capable to regenerate the wounded tissues and, in addition, the palms are not capable to recover the hole resulting of the injection. Consequently, the injections treatments can’t be repeated indefinitely because of the risk of creating necrosis or rotting

zones in the trunk that could lead to the inacceptable risk of falling palms.

A very simple method of injection of an emamectin benzoate formulation was developed in 2013 (Gomez and Ferry, 2015). With this method and this formulation it was established that it is possible to protect efficiently the palms during one year. Compared with the soaking treatments, the advantages of this method are considerable: one treatment per year, operation from ground level, no need of any special device, very safe treatment (no risk of contact for the operator, no dispersion of the product in the environment), simple and quick operation (2-3 minutes per palm). Consequently, in the countries where similar emamectin benzoate formulations are available, the cost of the treatment per palm and per year is at least 20 times less expensive than the soaking treatments. Unfortunately, in the European countries where this treatment is authorized, the multinational Syngenta that is the owner of the only authorized formulation has imposed a monopoly on the application of the treatment. This monopoly has led to make the treatment much more expensive than if the product had been normally placed on the market. Nevertheless, in France, thanks to CAVEM and Propalmes 83 negotiation efforts, Syngenta has accepted to divide per three the price of the treatment when it is applied inside municipality action plans.

Because of all its considerable advantages compared with the soaking treatments, the adoption of this treatment by an important number of palms owners becomes realistic. It will allow the area-wide implementation of this component of the IPM strategy that, as demonstrated in the second part of this paper, can contribute very efficiently to obtain the rapid decline of the RPW.

Theoretical Approach of the Impact of Injection Treatments to Obtain the Rapid Decline of the RPW

Equivalence between the decline of the RPW and the number of new infested palms

It is not possible to evaluate directly the RPW population decline. The decrease of the captures in the traps constitutes a useful indirect parameter, but the best parameter is the decline of the number of new infested palms. It is directly in relation with the decline of the RPW population.

Binomial distribution and confidence interval

The number of new infested palms depends of the initial number of infested palms, of the percentage of palms protected by injection in infested area and of the yearly reproduction ratio. This last one corresponds to the number of palms that should have been infested if no treatments were applied. When treatments are applied, a part of the palms in the infested area is not infested because not attacked by the RPP; another part is infested because the treatment is not applied on all the palms or is not 100% efficient; the last part is not infested because they are protected by the treatment.

As the efficiency of the treatment is very high developed by the Phoenix Research Station (Gomez and Ferry, 2015), the number of new infested palms (failed treatments) among the treated ones is very low (around 1% if we exclude the treatments applied on palms asymptomatic or not detected that were infested before injection. The treatment is not very efficient on such palms if the height of their stipe is of more than 3-4 m).

To simplify the model, we have neglected the number of failed treatments. We have also considered that the infested palms were killed one year after having been infested and so they were no more sources of new infestation after one year. In fact, this simplification has no much effect on the calculation as it does not modify the reproduction ratio.

The number M_{n+1} of new infested palms at the end of the year n+1, when the number of infested palms at the end of the year n was Mn=k, follows a binomial distribution with parameters (r*Mn, % of non treated palms). The formula is as follows:

$$P(M_1 = k) = \binom{M_0 * r}{k} * q^k * (1-q)^{(M_0 * r - k)}$$

For n>1, we apply the following Bayes formula:

$$P(M_{n+1} = k) = \sum_{j \geq 0} P(M_{n+1} = k \mid M_n = j) * P(M_n = j)$$

Where q = proportion of non-injected palms; r = reproduction ratio; Mo = the initial number of infested palms; M1, Mn+1 = the number of new infested palms at the end of respectively the first year and the year n+1, Mn = initial number of infested palms the year n+1; j and k respectively all the values ≤Mn+1 et ≤Mn; P(M1=k), P(Mn), P(Mn+1) = respectively the probability that M1 = k, Mn = k, Mn+1 = k); P(Mn+1=k | M1=j) = the probability that M2=k with M1=j

The inferior and superior limits of the confidence intervals at 95% correspond to the values of k for which the sum of the probabilities for the different values of k above and below these limits reaches 95%.

The reproduction ratio

In most of the European countries (excepted especially in the Canaries Islands-Spain), the intervention to control the pest was limited to the eradication of the infested palms, measure that, when it was applied, was applied generally very partially and only during the first 4-6 years after the detection of the first infested palms. Furthermore, it was considered that it was not possible to detect infestation early and impossible to save the infested palms (IVIA 2005; DRAAF 2007). However, the Phoenix Research Station established very soon that these two assertions were erroneous (Ferry and Gomez, 2008b) and that the regulation requiring the systematic eradication of whole infested palms was not at all necessary and would have a very serious counterproductive effect (Ferry and Gomez, 2007; Ferry and Gomez, 2008a). Because of this regulation, the eradication of the infested palms was implemented generally too late, when the palms were nearly killed by the RPW and had released the majority of the adults. Consequently, the propagation of the pest was not much affected by this measure during these first 4-6 years after the first RPW detection. Later, the situation became worse because the fight against the RPW was generally totally abandoned and the authorities even stopped to register the number of new infested palms.

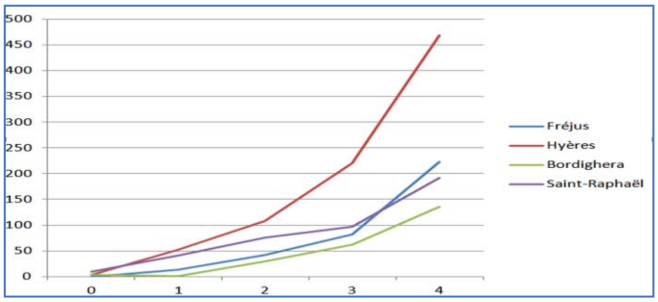

Figure 3. Number of new infested palms/per year in some cities of France and Italy.

The data on the number of new yearly infested palms, when they are available for the first 4-6 years, reflect relatively well the ratio of reproduction of the weevil when no treatment or inefficient treatments are applied. But available precise data on this number are not numerous. Figure 3 represents data available for some cities of France and Italy.

In Hyères and Bordighera, the cities of the palms, the number of new yearly infested palms was fairly well controlled and registered by the local authorities during the first 5-6 years, before, as in most of the European cities, they decide to abandon the control as they realized the ineffectiveness of their strategy. In the other two cities, the number of new yearly infested palms is based on the declaration of the palm owners but it is well established that the corresponding number under-estimated the reality.

Based on these data, it can be estimated that the reproduction ratio in the French Riviera is around 2, i.e. a doubling of the number of new infested palms each year during a first period. Of course, this ratio will decrease rapidly when the number of non-infested palms available in the infested area and around will reach a threshold that will lead the RPW to infest already infested palms in greater number than in the first period.

Evolution of the yearly number of new infested palms according to the percentage of palms protected by the injection treatment

Figure 4 represents the results of the calculation based on the formula mentioned above with a reproduction ratio of 2 and an initial number of infested palms of 500.

When only 50% of the palms are treated, the number of new yearly infested palms is constant but with an interval of confidence at 95% that enlarges quickly. When 75% of the palms are treated, we observe a very rapid decline: from 500 palms infested initially the number of infested palms decreases, at 95% of probability, between 19 and 45 after 4 years. The curve is quite similar to the one corresponding to the decrease of the number of new infested palms in the Canary Islands, Spain (Fajardo, 2017) that has led to the eradication of the RPW in this region in 7 years.

Nevertheless, our calculation shows that the number of new infested palms will not reach zero at 75% treated palms. This result leads to an important conclusion: to reach eradication, only with the preventive treatments, the percentage of treated palms must reach 100% after the 4th year. As the number of infested palms has decreased considerably, this option become perfectly feasible, even with more expensive and delicate treatments like soaking the palms with biological agents. Furthermore, complementary measures can be adopted because they have also become practically and economically feasible: intensive mass trapping, intensive inspection for early detection, immediate sanitation of the infested palms. Of course, this eradication success will be totally in vain if around the perimeter where the palms are treated, no similar action is implemented.

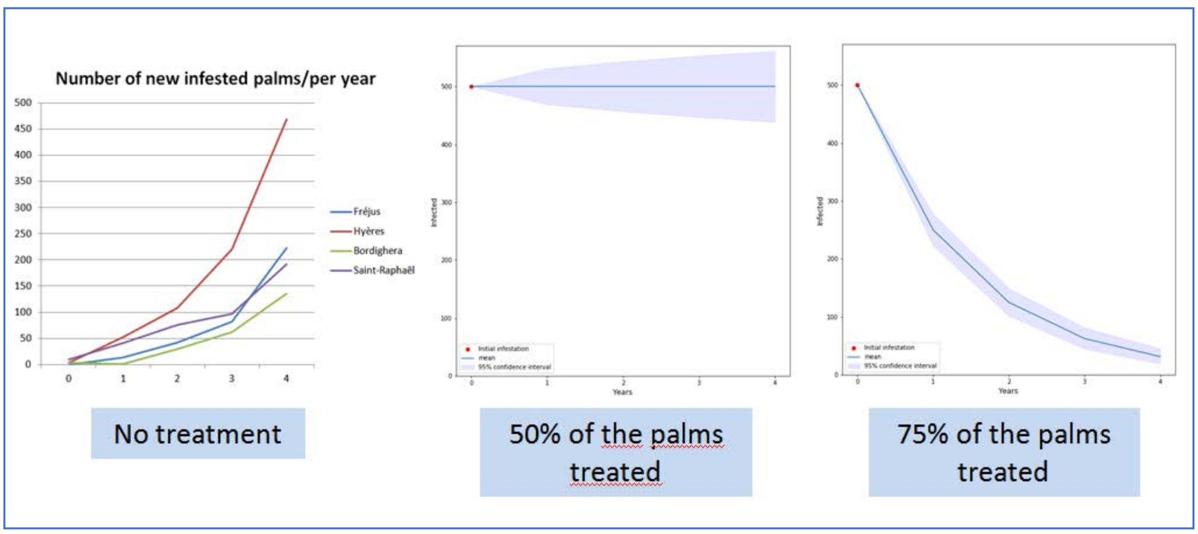

Figure 4. Evolution of the number of new yearly infested palms according to the percentage of injected palms.

Evolution of the infested areas when 75% of the palms are injected

Figure 5 simulates the evolution of the number of the new infested palms when 75% of 10000 palms are protected by injection and with 500 infested palms in year 0.

Each red circle corresponds to the new infested areas each year taking into consideration the aggregative character of the RPW dispersal. The repartition of the initially infested palms has been done randomly. The repartition of the new yearly infested palms has been done also randomly inside the new infested zone. For each year (Fig. 5-left), are indicated in blue, red, green and black, respectively the number of treated palms, the number of infested ones, the number of non-treated palms, and the number of dead palms.

We remember that to simplify the calculations, we have considered that the palms were killed after one year. We have also considered that no palms were present out of the limit of the perimeter. Consequently, the RPW originated from the infested palms had no other choice but infesting palms in the perimeter and that no RPW could come from outside the perimeter.

Nevertheless, these images simulate well what would occur in a municipality that treats 75% of its palms, if the municipalities around apply the same strategy. Very quickly the number of new infested zone and of new infested palms will decline, that will facilitate their location as the infested *Phoenix canariensis* become relatively quickly very visible. Treating all the palms in these remaining infested zone will become perfectly possible leading to the eradication of the RPW.

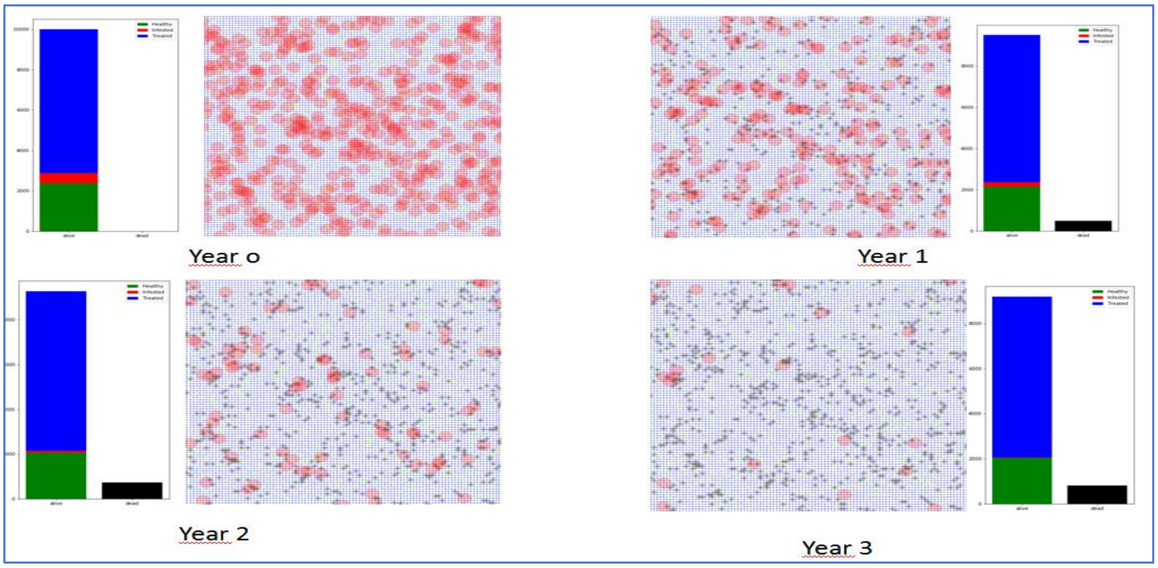

Figure 5. Rapid regression of the number of new infested palms and new infested areas (red circles) when 75% of the palms are injected.

First Results Obtained in the Framework of the ARECAP Project

In a territory which includes five grouped municipalities in the French Riviera (Fréjus, Saint-Raphaël, Roquebrunes-sur-Argens, Puget-sur-Argens, les Adrets de l'Esterel), a strategy elaborated by the Phoenix Research Station has been applied since 2016 and implemented under the supervision of the inter-municipality authority in charge of this territory (CAVEM). Although the area was very infested by the RPW, the objective was to demonstrate that it was possible in few years to stop the palms hecatomb and to obtain a rapid decline of the RPW.

The main challenge, here like everywhere, was to obtain the support of a maximum of palm owners to the proposed strategy and their collaboration. One essential point that contributed greatly to face this challenge was the existence of a very active association of private palms owners (Propalmes 83).

The action plan consisted of:

- Intensive and repeated communication and awareness (mail, media, meeting, hotline) campaigns.
- Website to assist the palms owners for implementing the treatments and to organize, group and register the treatments in coordination with the applicators.
- Management of red of monitoring traps with the assistance of volunteers palms owners.
- GIS to monitor permanently the implementation of the treatments, the results obtained, the evolution of the number of new infested palms in the whole territory, the evolution of captures in the traps, and to locate the priority sectors where efforts must be made to increase the percentage of treated palms and to obtain a quicker intervention on the infested palms
- Negotiation of the price with the company that imposed a monopole on the treatment.
- Geolocation of all the pinnate palms (essentially *Phoenix canariensis and Phoenix dactylifera)* by visual analysis of Google maps imageries.

The total number of pinnate palms was estimated at 15000. Taking into consideration that part of these palms were *Phoenix dactylifera* that are very rarely a RPW host when they are of great size and consequently were not injected, palms too small to be injected, nurseries palms that were treated by soaking treatments, it was estimated that around 50% of the *Phoenix canariensis* were treated by injection at the end of the first year.

In the case of CAVEM, as the location of the infested palms at the end of 2015 was unknown, it was not possible to concentrate the treatments in the potentially infested areas. Consequently, all the tall *Phoenix canariensis* of the territory was considered and the percentage of treated palms was calculated on the basis of total number of these palms. Figure 6 represents the results obtained.

Although the precision of this result is affected by the under-estimation of the number of new yearly infested palms (part of the palms owners do not declare infestation), it showed a clear trend: the number of new yearly infested palms instead of doubling as during the previous years remained similar in 2015 and 2016. The red vertical bar (Fig. 6) illustrates this brutal rupture in the evolution of the number of new infested palms. This result was conformed with the result presented in the theoretical approach when 50% of the palms are treated.

Figure 7 shows the number of palms that would have been infested in 2016 and 2017 if they had not been treated. For 2017, it was considered that the percentage of treated palms was also of 50%. It has been in fact higher. Regarding the conservation of a huge value patrimony, the benefit is evident: 1000 palms have escaped to the hecatomb.

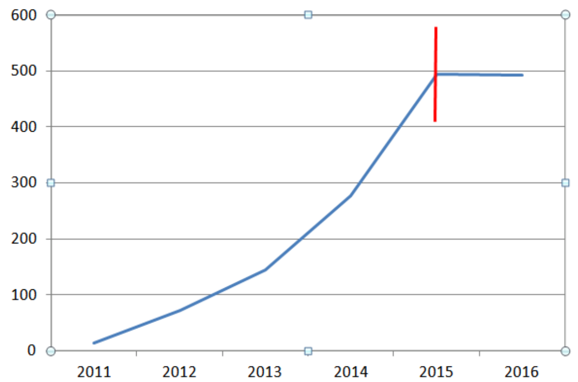

Figure 6. Evolution of the number of new yearly infested palms

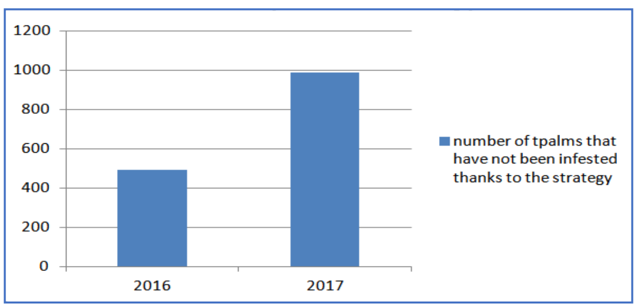

Figure 7. Number of palms that have been attacked but not infested.

Figure 8 shows the direct economic benefit that represented the implementation of these treatments. In this figure, has been represented the cost of eradication of the infested palms that would have been infested without the treatment (in blue) and the benefit (in red) that has resulted from the implementation of the treatments. The benefit has been calculated by substracting the cost of the treatments from the cost of eradication of the palms.

Financially, the benefit is great: it can be considered the municipalities and the private owners globally have saved nearly 500000 euros in 2016 and nearly 700000 euros in 2017.

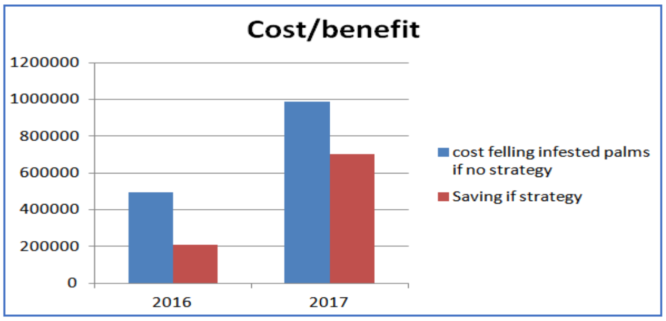

Figure 8. Direct cost/benefice analysis of the adopted strategy in 2016 and 2017.

Conclusions

The theoretical approach and the first results presented here demonstrate that the strategy proposed to obtain the rapid decline of the pest and to save the palms is feasible and efficient.

We have shown that it was feasible to organize a collective action when the political leaders are convinced and when the directly concerned stakeholders are involved.

Nevertheless, three points have to be highlighted:

- When the three other components of the IPM model (frequent inspection and rapid sanitation of infestation spots; mass trapping) are badly or not implemented, treating only 50% of the palms leads to an assured failure in the medium term. In case of seriously incomplete implementation of the strategy, the percentage of palms to be treated to obtain rapidly the decline of the RPW is at least of 75%. In CAVEM, the number of treated palms is now closer to this figure. In addition, the municipalities have adopted local regulations that could greatly contribute to the reduction of the number of abandoned infested palms. The number of traps is also now more important and they will also contribute to improve the efficiency of the action plan.
- Our calculation shows that the number of new yearly infested palms will not reach zero at 75% treated palms. This result leads to an important conclusion: to reach eradication, only with the preventive treatments, the percentage of treated palms must reach 100% after the 4th year. As the number of infested palms has decreased considerably, this option becomes perfectly feasible,

even with more expensive treatments like soaking bases of the leaves with biological agents. Furthermore, complementary measures can be adopted because they have also become practically and economically feasible: intensive mass trapping, intensive inspection for early detection, immediate sanitation or the infested palms.

- If such strategy is adopted in an area zone surrounded by other areas where there is no control of RPW, or it is inefficient, this strategy is doomed to fail.

It is then very urgent and important that CAVEM with the institutional support of Plant Protection Authority communicates the results obtained to convince other municipalities and palms owners in France and in Mediterranean region in general that the fight to save the palms is not lost.

In this paper, the palm species concerned was the *Phoenix canariensis*. But through the adaptation of the strategy and of the preventive treatments to the specificities of other palm species and context, including the date palm in the oasis, the principles of this proposal can be adopted (with a special attention regarding the issue of residue in dates when using injection technique with long insecticide and its possible metabolites persistence. For this reason, for date palm, emamectin benzoate is not appropriate).

On the technical issue, we would like to stress insist on the importance of implementing the preventive treatments only if they are efficient enough to obtain the rapid decline of RPW and are affordable for the majority of the palms owners. The treatment described in this paper is presently the only one that satisfies these two conditions. It obliges to treat with a chemical insecticide but, considering the safety and the short duration of its use (few years), we think that it is quite justified because of the importance of the challenge.

الملخص

فيريريشيل، رفائيل كوزنه، دانييل لابارن وأوليفيه ديفيرو. 2019. استراتيجية فعّالة وقائية للتخفيض في أعداد سوسة النخيل الحمراء على نحو سريع جداً في منطقة ما مزروعة بنخيل الزينة. مجلة وقاية النبات العربية، 37(2): 188-197.

لضمان نجاح مكافحة سوسة النخيل الحمراء فإنّه من الضروري تنفيذ برنامج متكامل وعلى نحو يؤدي إلى خفض تعداد الآفة بأسرع وقت ممكن؛ ويكون تحقيق هذا الهدف سهلاً في حال كانت وفرة العدد لسوسة النخيل الحمراء وانتشارها ما زال يتركز ضمن مناطق ضيقة. ولسوء الحظ، لم يعد الوضع كذلك بعد الآن في غالبية الدول التي ينتشر فيها الوباء. ويكمن التحدي الراهن في اقتراح استراتيجيات وحلول تقنية مستدامة اجتماعياً واقتصادياً وبيئياً. ومنذ عام 2006 فقد جرى في منطقة تضمّ 5 بلديات في الريفييرا الفرنسية تطبيق استراتيجية وضعت استناداً إلى مخطط بحوث النخيل (PRS) وتمّ تنفيذه تحت إشراف سلطات البلديات وبلدية منتون والبلديات المنطقة (CAVEM)؛ وعلى الرغم من كون المنطقة موبوءة بسوسة النخيل الحمراء فقد كان الهدف إثبات أنّه يمكن خلال بضع سنوات وقف تدهور النخيل وتخفيض أعداد هذه الآفة (تشير كلمة "نخيل" الواردة في متن هذا النصّ عموماً إلى نخيل الزينة *Phoenix canariensis* والذي يعدّ الهدف الرئيس والحاضن الأساسي لسوسة النخيل الحمراء). وكان التحدّي الأساس – كما هو في كلّ مكان – تحقيق تعاون مالكي النخيل والتزامهم بالاستراتيجية المقترحة؛ وإنّ إحدى النقاط الرئيسة التي ساهمت على نحو كبير بمواجهة هذا التحدّي تجسّدت بوجود رابطة نشطة جداً بين مالكي النخيل في القطاع الخاص بروبالمز 83/ Propalmes 83. وللحصول على تعاون مالكي النخيل في القطاعين العام والخاص كان أمراً جوهرياً أن يتمّ تبنّي تلك الاستراتيجية المقترحة آخذين بالحسبان القدرات والموارد الاقتصادية لهذه الجهات؛ وعلى ذلك فقد اقترحت مخطط بحوث النخيل (PRS) بأن تنظّم CAVEM الشراكات التسويقية التي يجتمع القائمين عليها ما أمكن بهدف تخفيض التكاليف إلى حدودها الدنيا. ومن بين تلك الشراكات فقد ركّزت مخطط بحوث النخيل (PRS) على اتخاذ المعاملات الوقائية المعتمدة على تقنية الحقن والخطّة العمل، نظراً لانخفاض تكاليف تطبيقها وكونها أكثر أماناً مقارنة بالتقنيات الأخرى. ويستند هذا المشروع على النتائج المتحصّل عليها من تحليل نظري يعرضه فيا- حول التطوّر في عدد الأشجار المصابة الجديدة سنوياً. ويستخدم هذا التحليل إيجاد العدد الدّال على الأشجار الجديدة المصابة سنوياً استناداً إلى النسبة المئوية للأشجار المعالجة، وذلك بنسبة احتمال 95%. وتؤكّد النتائج المتاحة في سلطة CAVEM لعام 2016 وجزئي العام 2017 على صحّة هذا التحليل. وتبيّن هذه النتائج أنّه إذا (كما هو مخطط) بلغ عدد أشجار النخيل التي تمّ حقنها ما نسبته 75% من العدد الإجمالي لهذه الأشجار فإنّ عدد أشجار النخيل المصابة سيتناقص سريعاً خلال 3-4 سنوات، وسيفضي إلى تراجع ملموس في حجم المجتمع الأبوي لسوسة النخيل الحمراء، وكذلك في عدد بؤر الإصابة والتي سيتمّ تحديدها بشكل قطعي أيضاً. وحالما يتحقّق الحصول على هذه النتائج، سيصبح من الممكن تماماً معالجة جميع أشجار النخيل حتى ولو بوجود عوامل مكافحة حيوية في بؤر الإصابة ليتمّ استئصال سوسة النخيل الحمراء في نهاية المطاف. وبطبيعة الحال، يتوجّب اتباع الاستراتيجية ذاتها بسرعة في المناطق المحيطة، وإلّا ستغدو هذه النتيجة عديمة الجدوى.

كلمات مفتاحية: *Rhynchophorus ferrugineus*، *Phoenix canariensis*، *Phoenix dactylifera*، الرقابة المتكاملة للآفات، معاملات الحقن، استراتيجية الإدارة، نهج تشاركي، كلفة قليلة، قليل ذو حقن متناقص سريع، استتباب المال، مع آلية التطوير.

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Efficacy of insect pathogenic fungi on mortality and development of *Rhynchophorus ferrugineus* (Olivier)

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Abstract

Wakil, W., M. Usman and S. Gulzar. 2019. Efficacy of insect pathogenic fungi on mortality and development of *Rhynchophorus ferrugineus* (Olivier). Arab Journal of Plant Protection, 37(2): 198-199.

Fifteen different isolates of entomopathogenic fungi including *Beauveria bassiana*, *B. brongniartii*, *Metarhizium anisopliae* and *Purpureocillium lilacinum* were tested for their effectiveness against different developmental stages of red palm weevil *R. ferrugineus*. After 21 days of exposure, *B. bassiana* isolates (WG-23 and WG-25) caused 100% mortality in larvae while only WG-25 resulted in 100% mortality against *R. ferrugineus* adults. Furthermore, WG-25 reduced egg hatching up to 81.49% at 1×10^8 conidia ml^{-1}.

Keywords: Red palm weevil, entomopathogenic fungi, mortality, horizontal transmission, sub lethal effects, progeny.

Introduction

The invasive red palm weevil *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae) is recognized as one of the most serious threat to date palm plantation (Dembilio and Jaques, 2015; Tagliavia *et al.,* 2014; Wakil *et al.,* 2015). It has been reported in 50% of date producing countries (El-Mergawy and Al-Ajlan, 2011), also it is a serious pest of date palms in Pakistan (Mohan, 1917). The aim of this study is to explore fifteen different isolates of entomopathogenic fungi including *Beauveria bassiana*, *B. brongniartii*, *Metarhizium anisopliae* and *Purpureocillium lilacinum* against different developmental stages of *R. ferrugineus*.

Screening Bioassays

During initial screening bioassays, both developmental stages were found susceptible towards all tested 15 isolates causing 14.9-81.5% and 5.6-51.7% mortality against larvae and adults, respectively.

Virulence Bioassay

The most effective top five potential isolates from screening bioassays were further evaluated against 6th instar larvae and adults of *R. ferrugineus* using four different concentrations (1×10^6; 1×10^7; 1×10^8; 1×10^9 conidia ml^{-1}) and mortality was recorded at 7, 14 and 21 days after treatment. After 21 days of exposure, WG-23 and WG-25 caused 100% mortality in larvae while only WG-25 resulted 100% mortality against adults. The virulence bioassay showed positive correlation with time and concentrations. Our results are in agreement with those of Verde *et al.* (2015) who showed that *B. bassiana* caused significant mortality against larvae and adults resulting in 88-92% and 20-26% mortality, respectively. Similarly, Francardi *et al.* (2012) tested the entomopathogenic fungi against the larvae and adults of *R. ferrugineus* and observed 100% and 90% mortalities, respectively. Likewise, Dembilio *et al.* (2010) verified that *B. bassiana* can significantly infect the 4th instar larvae and laboratory adults with calculated LC_{50} values of 6.3×10^7 and 7.2×10^8 conidia ml^{-1}, respectively. We also found that potential isolates were not only effective against larval and adult stages, but also showed ovicidal effects, as WG-25 reduced egg hatching up to 81.49% at 1×10^8 conidia ml^{-1}. Similar to our results, Dembilio *et al.* (2010) confirmed that *B. bassiana* considerably infected the eggs of *R. ferrugineus* (LC_{50} 1.5×10^8 conidia ml^{-1}). Likewise, Verde *et al.* (2015) evaluated different *B. bassiana* isolates against eggs of red palm weevil and observed 26.8-41.2% reduction in egg hatching compared with the control.

Auto-dissemination Bioassay

In auto-dissemination bioassay, it was confirmed that fungal infected adults have ability to transmit the disease to healthy ones. The effective isolate (WG-25) reduced the number of eggs per female/day (0.5 eggs/day), fecundity (11.7 eggs/female), eggs survival (11.6%) and larval survival (25.9%) when treated males mated with treated females compared with the control treatment. Similarly, Dembilio *et al.* (2010) proved that *B. bassiana* caused >62.6% and 32.8% reduction in fecundity and egg hatching, respectively with overall 78% reduction in progeny among different pairing combinations. The present study revealed that entomopathogenic fungi have a great potential to control the different developmental stages of *R. ferrugineus* and may become an integral part of successful IPM program of date palm insect pests.

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الملخص

وقاص وكيل، محمد عثمان وسريه ريش غول زار. 2019. تأثير فطور ممرضة للحشرات في موت وخصوبة سوسة النخيل الحمراء وكفاءتها التناسلية. مجلة وقاية النبات العربية، 37(2): 198-199.

تمّ اختبار فعالية 15 عزلة مختلفة من الفطور الممرضة للحشرات (*Beauveria bassiana*، *B. brongniartii*، *Metarhizium anisopliae*، *Purpureocillium lilacinum*) إزاء سوسة النخيل الحمراء *Rhynchophorus ferrugineus* الى مختلف أطوار نموّها. وبعد انقضاء 21 يوماً من التعريض فقد تسببت عزلتا الفطر *Beauveria bassiana* WG-23 و WG-25 بنسبة موت بلغت 100% لليرقات؛ إلاّ أنّ العزلة WG-25 كانت الوحيدة التي حققت نسبة موت بلغت 100% عند استخدامها على الحشرات الكاملة لسوسة *R. ferrugineus*. وعلاوةً على ذلك فقد خفّضت العزلة WG-25 من خصوبة وقدرة الحشرات على وضع البيض بمقدار وصل حتى 81.49% عند استخدام تركيز 1 × 10^8 بوغة كونيدية/مل.

كلمات مفتاحية: سوسة النخيل الحمراء، الفطور الممرضة للحشرات، موت، انتقال أفقي، تأثير تحت مميت، نسل.

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Is the use of entomopathogenic fungi a viable option for the control of Red Palm Weevil?

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Abstract

El Bouhssini. M., A.N. Trissi and Z. Kadour. 2019. Is the use of entomopathogenic fungi a viable option for the control of Red Palm Weevil?. Arab Journal of Plant Protection, 37(2): 200-202.

During the period 2010-2014, a survey of entomopathogenic fungi of red palm weevil (RPW) in the coastal areas of Syria were characterized and their efficacy against RPW was investigated. In addition, the naturally existing endophytes in palm trees were investigated. Promising results for the control of RPW were obtained under semi-field conditions using *B. bassiana* isolates. The big challenge for the different researchers working with entomopathogenic fungi is to have this type of high efficacy in the field where generally temperature is high and relative humidity is low. The potential use of *B. bassiana* endophytes was also discussed.

Keywords: Red pam weevil, date palm, entomopathogenic fungi, endophytes.

Introduction

Red palm weevil (RPW), *Rhynchophorus ferrugineus* (Olivier), (Coleoptera: Curculionidae) is one of the most destructive pests of palm trees worldwide (Dembilio and Jaques, 2015; Faleiro *et al*., 2016). Several management strategies for the control of RPW have been developed and tried in different parts of the world. However, biological control is the component of integrated pest management (IPM), which has not been fully explored for the control of this pest. Entomopathogenic fungi (EPF) have been found to be promising bioagents in IPM programs against several insect pests. EPF have also been found as endophytes in a diversity of crops (Vega *et al*., 2009). Colonization of date palm by *B. bassiana* and *Lecanicillium* spp. enhances plant defence and stress response (Gómez-Vidal *et al*., 2009), and provides plant growth promotion benefits (Jaber and Enkerli, 2016). Using endophytic isolates, in some cases, have resulted in complete control of the target pest (Quesada-Moraga *et al*., 2006). However, endophytes are still poorly explored as a management option for systemic protection of palms against *R. ferrugineus*.

Survey of RPW Entomopathogenic Fungi

A survey of entomopathogenic fungi of RPW in the coastal areas of Syria in 2010, 2011 and 2012 seasons was carried out. The collected isolated were characterized and their efficacy against RPW was investigated. In 2014, another survey was conducted to investigate the naturally existing endophytes in palm trees. Healthy peripheral leaves from 5-15-year-old palms were cut, surface sterilized and assessed for colonization by EPF. More than 4230 samples of different stages of RPW were collected. These insects were placed in plastic containers and killed by freezing. Dead insects were surface sterilized, incubated for 2 weeks to observe fungal outgrowth and then were identified. Twelve fungal isolates of *Beauveria bassiana*, and one isolate of *Lecanicillium* sp. were obtained.

Characterization of *B. bassiana* Isolates

The characterization of *B. bassiana* isolates showed that the best fungal growth, in vitro, was at 25˚C, and the higher productivity of conidial spores was at 20˚C. The pathogenicity test of three *B. bassiana* isolates (BBS, $RPWSL_5$ and GHA) against red palm weevil adults showed highest insect mortality of 93.75% and 100% after 14 days of application with the $RPWSL_5$ isolate when concentration 1×10^7 and 1×10^8 conidia ml^{-1} were used, respectively. Moreover, The LC_{50} values varied from 2×10^5 to 1×10^9 conidia ml^{-1}, depending on the isolate. The lowest LC_{50} was 2.12×10^5 (1.3×10^5- 3.2×10^5) conidia ml^{-1} when insect was treated with $RPWSL_5$ compared with 7.1×10^8 (5.1×10^8- 1×10^9) conidia ml^{-1} when GHA (commercial isolate) was used. The LT_{50} values varied from 3.5 to 28.6 days, depending on the isolate. The shortest LT_{50} value (3.5 days) was obtained with $RPWSL_5$ at 1×10^7 conidia ml^{-1}. The longest LT_{50} (28.64 days) was obtained with BBS at 1×10^7 conidia ml^{-1}. Results obtained showed that there are entomopathogenic fungal isolates effective against the different stages of the RPW under laboratory conditions. Similarly, many laboratory studies showed that EPF caused high mortality (80–100 %) of RPW larvae and adults (Francardi *et al*., 2013; Gindin *et al*., 2006; Merghem, 2011). Promising results for the control of RPW were also obtained under semi-field conditions using *B. bassiana* isolates (Dembilio *et al*., 2010; El-Sufty *et al*., 2009), *Lecanicillium* (*Verticillium*) *lecanii* (Sabbour and Solieman, 2014) and *Isaria fumosorosea* (Sabbour and Abdel-Raheem, 2014). The big challenge for the different researchers working with entomopathogenic fungi is to have this type of high efficacy in the field where generally temperature is high and relative humidity is low. In addition, because the larvae are hidden

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within the host, it may be difficult to get them infected by EPF. Other researchers tried using attract and infect strategy of RPW adult (Dembilio *et al*., 2010; Yasin *et al*., 2017).

Characterization of *B. bassiana* Endophytes

Three *B. bassiana* entophytic isolates were isolated from healthy palm trees from the coastal area of Syria. Similarly, (Gómez-Vidal *et al*., 2006) reported the potential of *B. bassiana*, *L. dimorphum* and *L. psalliotae* as endophytes in the young and adult date palm petioles; fungi were detected microscopically inside the parenchyma and sparsely distributed within vascular tissue without the date palm showing any negative effect. Gomez-Vidal *et al*. (2009), hypothesized that entomopathogenic fungi growing endophytically in palms modulate plant defence and could promote palm growth. The three *B. bassiana* endophytic isolates we identified have not yet been tested for their efficacy against RPW. However, we do believe that more research focus should be placed on endophytic isolates, as they seem to present better potential as biocontrol agents for RPW: delivery systems to the target pest should be easier and might not be exposed to the same harsh climatic conditions compared to entomopathogenic fungi.

الملخص

البوحريني، مصطفى، عبد النبي بشير وظلال قدور. 2019. هل يمكن استخدام فطور ممرضة للحشرات كأداة للتطبيق لمكافحة سوسة النخيل الحمراء؟. مجلة وقاية النبات العربية، 37 (2): 200-202.

خلال الفترة 2014-2010 ... سوسة النخيل الحمراء ... إزالة ... سوسة النخيل الحمراء. ... الحشرات داخل أشجار النخيل ... *B. bassiana*. ... سوسة النخيل الحمراء ... درجات الحرارة ... *B. bassiana* ... النخيل ...

كلمات مفتاحية: سوسة النخيل الحمراء، النخيل، الفطور الممرضة للحشرات، داخل النبات.

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Red palm weevil monitoring and early warning system

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Abstract

Cressman, K. 2019. Red palm weevil monitoring and early warning system. Arab Journal of Plant Protection, 37(2): 203-204.

To improve effective and sound decisions related to red palm weevil management, FAO has developed an initial beta version of a global RPW monitoring and early warning system to help farmers and national authorities respond to this important transboundary pest on date, coconut and ornamental palms in Africa, Asia and Europe. The system consists of the SusaHamra mobile application for data collection in the field and a GIS-based online platform for data analysis and mapping.

Keywords: RPW, monitoring, forecasting, warning system.

Introduction

There are currently very few tools available that can be used to systematically collect standard geo-referenced data in the field for the regular monitoring and management of the Red Palm Weevil (RPW) (Cressman and Viprathi, 2017; FAO 2017a). In the absence of such data and analysis, it is nearly impossible to take effective and technically sound decisions (Fajardo *et al.,* 2017; FAO2017b). To address this critical shortcoming, FAO has developed an initial beta version of a global RPW monitoring and early warning system to help farmers and national authorities respond to this important transboundary pest on date, coconut and ornamental palms in Africa, Asia and Europe. The system consists of the SusaHamra mobile app for data collection in the field and a GIS-based online platform for data analysis and mapping. Based on lessons learned from FAO's long experience in developing and operating global monitoring and early warning systems for Desert Locust and more recently for the Fall Armyworm, the mobile app for smartphones has been developed as a tool that can be used every time palms are inspected or treated, or when pheromone traps are checked for RPW. The collected data feed into a centralised database for mapping and analytics that show the current situation and its geo-temporal spread. The data will be valuable to decision-makers and researchers within countries and throughout the world. In addition, FAO is developing a protocol for mapping palm farms based on remote sensing and machine-learning, artificial intelligence that will be integrated into the system to supplement analysis of the field data. SusaHamra will also include educational material on RPW and its management, and be available in English, Arabic and other local languages. The RPW monitoring and early warning system has been designed in a dynamic manner in order to account for the changing needs of users and countries over time. FAO offers its unique role in developing and maintaining a global tool that can provide impartial and unbiased advice to countries or farmers in a sustainable manner.

SusaHamra mobile application

The beta version of the app consists of three sections: information, palms and traps. The information section contains the name of the field, the date of the inspection and the type of inspection (palms or traps). The palms section contains data on the presence/absence of RPW, visible symptoms, tissue damage, inspection method, control undertaken and by whom. The traps section contains data on catches and trap servicing (by whom, last date, lure replacement).

Users must first register before they can use the app. The one-time only registration process consists of entering basic information about the farm, palms and traps. New palms and traps can be entered at any time. This will allow easy inspections of individual palms and trap in order to monitor the distribution and spread of RPWM in farms. The app is initially available in English and Arabic. It is free and will be eventually available for download from the Google Play Store and the Apple App Store.

There are also specific user modes for data validation module to maintain a high level of data quality and for additional language translations.

Substantial field testing, validation and refinement are to be done before SusaHamra is ready for release and operational use. The first field evaluation was carried out in March 2019 in Oman. This will be further refined and additional feedback will be obtained from users in other countries before finalizing the app.

SusaHamra should be used every time palms and traps are inspected for RPW.

Global platform

The global platform consists of a centralised database in the cloud and maps and graphical analytics for the presentation and analysis of the data collected by SusaHamra. The platform is managed by FAO Headquarters in Rome and utilises PowerBI software. The geo-referenced data are presented as maps, graphs and data tables. The maps can be

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zoomed from the global to country, province and farm level. The corresponding analytical graphs will be displayed. If a specific country, province or farm is selected, the graphs and data tables will change accordingly. This is an easy way not only to display data but to see data relationships such as RPW presence and inspection method or visible symptoms, or RPW catches by lure or trap type. An example of the platform is the Fall Armyworm Monitoring and Early Warning System (FAMEWS) that was developed and maintained by FAO (www.fao.org/fall-armyworm).

Palm mapping

FAO is using a machine-learning, artificial intelligence approach to map individual palm trees based on Google Tensor Flow and lessons learned from the FAMEWS Nuru app (www.fao.org/fall-arymworm/) by Penn State University. This approach relies on thousands of palm photos that are used for learning by the computer. This knowledge is then applied to high-resolution geo-referenced satellite imagery and digital photography to map the palms. The initial work focuses on two sample areas, one that consists homogenous of palm farms (Gassim, Saudi Arabia) and one that is more urban and heterogenous (Al Ahsa, Saudi Arabia). The results will be upscaled and applied to larger areas in order to provide a base map of individual palms that can be used in SusaHamra, the global platform and geographic information systems.

Conclusion

The development of the RPW monitoring and early warning system is funded by FAO seed money, supplemented by contributions to the Global RPW Trust Fund. The system is flexible and adaptable to meet users' constantly changing needs. The SusaHamra mobile app and global platform, are made available to the global community for free as tools to more effectively monitor and manage RPW. There are no registration, monthly subscription, data storage or product fees, which sets apart this system from commercial products and services. In addition, hosting the data and global platform at FAO ensures sustainability and free access within a secure environment that does not compromise individual privacy. FAO remains a trusted, non-profit partner with global reach. It is objective, impartial, unbiased, apolitical and neutral. It uses cutting-edge and the latest innovative technologies to develop free tools, systems and platforms that can quickly and easily be upscaled. FAO has more than 75 years of Desert Locust monitoring and early warning experience that can also be applied to similar systems for RPW.

الملخص

كريسمان، كيث. 2019. رصد سوسة النخيل الحمراء ونظام الإنذار المبكر. مجلة وقاية النبات العربية، 37(2): 203-204.

سعياً لإحراز تقدّم في قرارات ذات صلة ... إدارة سوسة النخيل الحمراء فقد طوّرت منظمة الأغذية والزراعة التابعة للأمم المتحدة (الفاو) نظام رصد وإنذار مبكر لسوسة النخيل الحمراء بغرض مساعدة مزارعي النخيل وسلطات ... على حدود ... (SusaHamra) ... المحمول ...

الكلمات المفتاحية: سوسة النخيل الحمراء، مراقبة، تنبؤ، أنظمة الإنذار المبكر

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The economic impact of red palm weevil *Rhynchophorus ferrugineus* Olivier in Egypt

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Abstract

Abbas, M.K. 2019. The economic impact of red palm weevil *Rhynchophorusf errugineus* Olivier in Egypt. Arab Journal of Plant Protection, 37(2): 205-205.

The red palm weevil (RPW) *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae) is a palm borer introduced to the Arab World, and was first recorded in 1992 in Egypt in date palm plantations of Sharkia and Ismailia Governorates. The infestation now covers all 26 governorates in Egypt, with infection rates from 2% to 35%. Date palm is considered of economic importance in Bahria and Siwa oases and Aswan with infestation rate exceeding 20%, and the highest infestation rate was recorded in 2014 on more than 250,000 infested date palm trees. The most important control measures applied were pesticides spraying and injection, palm removal, prevention of spread through offshoots, agricultural extension and aggregation pheromone trapping in some areas. The cost of control operations in Sharkia and Ismailia Governorates were around 10 million Egyptian pounds (around 3 million USD) during the period from 1992 to 2000, which included the use of 160 tons of pesticides (more than 25 tons per year) as well as fuel, sprayers, and labor. The estimated total cost per year in Egypt was around 354 million Egyptian pounds (20 million USD) which include labor cost of periodic monitoring (2700 persons to investigate 6000 palm trees/person/month, with a cost 4.55 million USD per year), protective spraying during March and November (13.4 million USD), and quarantine operations, removal of highly infested palms and eradication with a total cost around 2-3 million USD, and funding was not always available which lead to increased damage. The estimated total loss since 1992 untill now is around 4 billion Egyptian pounds (400 million USD), taking into consideration the cost of replantation, removal of highly infested palms and control operations, in addition to the negative impact on 100 date factories due to reduction in the total amount of dates processed.

Keywords: Red palm weevil, removal, economic loss, quarantine.

الملخص

عباس، محمد كمال. 2019. الأثر الأقتصادي لسوسة النخيل الحمراء في مصر. مجلة وقاية النبات العربية، 37(2): 205-205.

تعدّ سوسة النخيل الحمراء *Rhynchophorus ferrugineus* Olivier من حشرات النخيل الدخيلة على الوطن العربي، وسجلت أول مرة في مصر في مزارع نخيل بمحافظتي الشرقية والإسماعيلية في العام 1992؛ وتنتشر الإصابة حالياً في 26 محافظة في مصر بنسبة إصابة 2-35%. يعتبر نخيل التمر محصول رئيسي في الواحات البحرية وسيوة وأسوان حيث تصل نسبة الإصابة إلى أكثر من 20%، وقد سجلت أعلى نسبة إصابة عام 2014 لتشمل أكثر من 250 ألف نخلة مصابة. وكانت أهم تدابير المكافحة المطبقة لذلك: رش وحقن المبيدات الكيميائية، إزالة أشجار النخيل المصابة بشدة، منع انتشار الآفة عبر الفسائل، الإرشاد الزراعي واستخدام مصائد الفرمون في بعض المناطق. بلغت تكلفة عمليات المكافحة في محافظتي الشرقية والإسماعيلية حوالي 10 ملايين جنيه مصري (ما يقارب 3 مليون دولار أمريكي) خلال الفترة 1992-2000 والتي شملت استخدام 160 طنا من مبيدات الآفات (أكثر من 25 طن في السنة) بالإضافة إلى تكلفة الوقود والرشاشات والعمال. قدّرت التكلفة الإجمالية السنوية للمكافحة في مصر بحوالي 354 مليون جنيه مصري (20 مليون دولار أمريكي)، والتي تضمنت: تكلفة العمالة للفحص الدوري (2700 فاحص، بمعدل 6000 شجرة نخيل/فاحص/شهر، والتي بلغت 4.55 مليون دولار سنويا)، والرش الوقائي الشهري آذار/مارس وتشرين الثاني/نوفمبر (13.4 مليون دولار)، الحجر الزراعي، إزالة وتقطيع النخيل المصاب بشدة) حوالي 2-3 مليون دولار؛ وقد أدى عدم توفر التمويل بشكل منتظم إلى تفاقم الإصابة. وبلغت قيمة الخسائر المقدرة منذ عام 1992 ولغاية تاريخه حوالي 4 مليار جنيه مصري (400 مليون دولار أمريكي)، مع الأخذ بالحسبان تكلفة إعادة الزراعة، وإزالة أشجار النخيل المصابة بشدة، وعمليات المكافحة فضلا عن التأثيرات السلبية التي طالت 100 مصنع إنتاج التمور جرّاء تراجع الكمية الإجمالية للتمور المصنّعة.

كلمات مفتاحية: سوسة نخيل حمراء، إزالة، خسارة اقتصادية، الحجر الزراعي.

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