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REVIEW ARTICLE

Review on the management of red palm weevil *Rhynchophorus ferrugineus* olivier in date palm *Phoenix dactylifera* L

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ABSTRACT

Red palm weevil, *Rhynchophorus ferrugineus* (Olivier) is a key pest of date palm *Phoenix dactylifera* L and continues to spread among and within date palm plantation countries. Globally, *R. ferrugineus* has the widest geographical range among the genus of *Rhynchophorus* weevils and is known to cause complete destruction of palms often resulting in widespread damage to entire grooves of cultivated date palms. Since *R. ferrugineus* was first recognized as a threat to date palm production in the mid 1980s for GCC countries, scientists and growers have deployed several methods to control this destructive pest, with the use of chemical insecticides being the main strategy until the synthesis of the male aggregation pheromone in 1993. This article reviews the current literature on different control methods to evaluate the effectiveness of various control options and proposes an overall strategy to manage *R. ferrugineus* in date palm. The *R. ferrugineus* control methods include prospects of early detection techniques, role of phyto-sanitation and agro-techniques (palm and field sanitation, palm injury prevention, elimination of hidden breeding sites including abandoned date plantations), semiochemicals and insecticide applications in preventive and curative treatments. Further, case studies of area-wide *R. ferrugineus* management in date palm besides the potential of biological control methods particularly with regard to the use of entomopathogenic fungi and nematodes and also the role of regulatory methods to regulate transport and transfer of infested palm trees (domestic and international quarantine) is presented. A review of the available control methodologies suggests that *R. ferrugineus* can be managed by deploying an Integrated Pest Management (IPM) strategy comprising of several tactics including regulatory methods, behaviour manipulation involving insect aggregation pheromones for monitoring and mass trapping adult weevils, chemical and biological control, crop and field sanitation, eliminating hidden breeding sites, manipulation of cultural practices involving in-groove humidity and palm density, frond and offshoot removal, besides regular dissemination of *R. ferrugineus*-IPM technologies among farmers and pest managers.

Keywords: Date palm; *Rhynchophorus ferrugineus*; Red palm weevil; IPM

INTRODUCTION

Date palm *Phoenix dactylifera* L is an important fruit crop in the palm family (Arecaceae) cultivated in the arid regions of the world including the Arabian Peninsula, Middle East and North Africa since pre-historic times where it is closely associated with the life and culture of the people. It is estimated that there are 100 million date palms cultivated in an estimated 1 million hectare (Table 1) predominant in the Arab countries of the Middle East and North Africa (FAOSTAT 2013).

The crop is known to withstand several biotic and abiotic stresses. The successful future development of date palm depends largely on evaluating, utilizing and conserving genetic resources; assessing the value of present and potential cultivars, promoting the best cultivation practices, processing, marketing practices and widening the number of fruit and fruit products (Johnson et al., 2015 a & b). Besides being a very good source of food, dates are reported to have several medicinal qualities *viz.* antibacterial, antifungal, antitumor, antiulcer and immuno-modulatory properties. The antioxidant activity of some date palm cultivars has been attributed to phenolic compounds (Vayalill 2002; Al-Farsi et al., 2005; Baloch et al., 2006; El-Hadrami and Al-Khayri 2012). The global date production has increased from just 1.8 million tons in 1962 to 7.5 million tons in 2013 (FAOSTAT 2013). During

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Table 1: Area under date palm and production of dates in major date producing countries (FAOSTAT 2013. http://faostat3.fao.org/download/Q/QC/E)

Country	Area (ha)	Production (million tonnes)
Algeria	164,695	848,199
Egypt	45,883	1,501,799
Iran	162,998	1,083,720
Iraq	125,000	1,083,720
Libya	33,877	174,040
Morocco	59,229	107,611
Pakistan	89,654	526,749
Saudi Arabia	168962	1,065032
Oman	32,000	269,000
Tunisia	53,000	195,000
UAE	48,000	245,000
Total	983,298 (1.0 million ha)	6,692,261 (7.0 million tons)

the last two decades there has been a significant increase in the area under date palm with several new plantations cultivated in vast monoculture stretches that offer an ideal ecological niche for biotic stresses to manifest, including insect pest and diseases.

A recent report on the arthropod fauna of date palm, enlists 112 species of insects and mites associated with date palm worldwide including 22 species attacking stored dates (El-Shafie 2012). Significant among these being the red palm weevil, *Rhynchophorus ferrugineus* (Olivier 1790) (Coleoptera: Curculionidae) which was first detected in the Middle East during 1985 in Ras Al-Khaima of the Gulf state of the United Arab Emirates from where it spread to other date producing countries in the region and beyond mainly through infested planting material (Kehat 1999; Zaid 2002; Faleiro et al., 2012; Al-Shawaf et al., 2013). Worldwide *R. ferrugineus* is currently reported from all the continents, attacking 40 palm species world wide of which coconut, date palm and the canary island palm are important (Anonymous 2013; Faleiro 2006). Molecular-genetics of pest palm weevil populations confirm that the weevil recorded in Laguna Beach, California, USA during 2010 is the *R. vulneratus* (red stripe weevil) and not *R. ferrugineus* (Rugman-Jones et al., 2013)

In older date plantations where irrigation may be scarce the long horn beetle, *Jebusea hammerschmidti* Reich is emerging as a challenge. The scarabid beetle *Oryctes* spp though abundant on date palm is not life threatening. The old world date mite *Oligonychus afrasiaticus* (McGregor) also known as the dust mite is a serious pest of date palm fruits in date palm. Heavy infestations can cause significant yield reductions, because the scars and the webs that are formed on the exo-carp of the unripe fruits render them unfit even for consumption. The lesser date moth, *Batrachedra amydraula* is an important pest of date fruits in areas with high relative humidity often causing more than 50% damage which results in direct loss of yield. Further, the hemipteran dubas date bug, *Ommatissus lybicus* is also an important pest of date palm in some countries.

R. ferrugineus is a hidden and lethal tissue borer of date palm with infested palms in the early stage of attack extremely difficult to detect. However, these palms respond to chemical treatment (stem injection) and can be saved unlike palms in the advanced stage of attack, where larvae cause extensive tissue damage often rendering such palms beyond any treatment and have to be eradicated. In date palm infestation mostly occur at the base of the trunk near the soil (Abraham et al., 1998; Sallam et al., 2012), while in *P. canariensis* the crown of the palm is usually attacked making detection extremely difficult and challenging (Dembilio et al., 2012).

Date palm growers spend a substantial amount of their income on a variety of control methods trying to eradicate this weevil. This article is intended to provide a review of the current control methods, and recommend an effective multi-faceted approach to manage *R. ferrugineus*. Case studies of *R. ferrugineus*-IPM in date palm are also presented.

BACKGROUND

Red Palm Weevil was first described as a harmful insect on the Indian coconut palm in 1906 (Lefroy 1906), and the date palm tree in 1917 (Brand 1917). It was then discovered in the Gulf Region in the mid 1980s, from where it spread rapidly to several date producing countries through infested planting material that is mainly transported for ornamental gardening (Faleiro et al., 2012). Red palm weevil has dramatically spread worldwide with an expanded geographical range (Giblin-Davis et al., 2013), and is now reported from several Asian, African, European and American countries (AL-Ajlan 2008; OEPP/EPPO 2005; Giblin-Davis et al., 2013). Although the California Department of Food and Agriculture reported *R. ferrugineus* from the Laguna beach area in California (CDFA 2010), molecular studies by Rugman-Jones et al. (2013) from the University of California, Riverside, USA confirmed that the weevil species reported from Laguna beach is the red stripe weevil, *R. vulneratus* and not red palm weevil, *R. ferrugineus*.

Life cycle

R. ferrugineus completes its life cycle inside the trunk of the palm. It has four life - stages (complete metamorphosis), which includes eggs, larva, pupa, and adult stage. In general, all types of palm trees support the growth and development of the red palm weevil during all stages of its life. The life cycle begins when the female weevils lay about 300 creamy white eggs (2.6 mm in length and 1.1 mm of width) inside cracks and crevices on the palm trunk. Gravid female weevils are attracted to young date palms less than 20 years old (Abraham et al., 1998) for egg laying which is enhanced due to palm tissue volatiles emitted on fresh injuries on the palm resulting from frond shaving and offshoot removal. The eggs hatch in from 2 to 5 days. The resulting conical legless larvae continue to grow in the palm trunk for 1 to 3 months. They feed primarily on palm tissue and move inwards towards the soft heartwood at the center of the palm trunk. A complete larva (50 mm in length and 20 mm of width) has a yellowish-white body and a reddish-brown head with strong mandibles that help bore the palm trunks. When fully grown, the larva forms a cocoon about 35 mm long and 15 mm wide. After 14 to 21 days in pupal stage the insect becomes an adult (imago) 35 mm long and 12 mm wide, reddish-brown in colour with black spots on the thorax, a long proboscis, and a pair of antenna on the front of its head. Adult male weevils are characterised by a tuff of bristles on the dorsal tip of the snout. Adult weevils feed outside the palm trunks and can live an average of 98 days (between 29 to 153 days) (Wattanapongsiri 1966; Avand Faghih 1996; Abraham et al., 2001).

Host range and symptoms of infestation

R. ferrugineus is reported to attack 40 palm species worldwide (Anonymous 2013), with the canary island date palm, *Phoenix canariensis*, date palm, *P. dactylifera* and coconut palm, *Cocos nucifera* being among the most widely preferred hosts (Faleiro et al., 2014). According to Abraham et al 1998 a *R. ferrugineus* infested date palm exhibits one or more of the following symptoms *viz*., oozing of brownish fluid together with palm tissue excreted by feeding grubs which has a typical fermented odour, drying of infested offshoots, tunneling of palm tissue by grubs, presence of adults and pupae at the base of fronds, pupae around an infested palm, drying of outer leaves and fruit bunches and toppling of the trunk in case of very severe and extensive tissue damage (Fig. 1). *R. ferrugineus* population is highly aggregated in nature which results in infestations occurring in clusters (Faleiro 2006), often by invading adults that fly short distances (Ávalos et al., 2014; Hoddle et al., 2015) which could also play a role in the aggregation of this pest. Prevailing climatic conditions influence weevil activity. In the Middle East peak weevil activity is recorded between March and May while a second peak in captures occurs during October and November (Abraham et al., 1998; Vidyasagar et al., 2000; Soroker et al., 2005).

Fig 1. Red palm weevil infested date palms in the early (a) and advanced (b) stages of attack (Photo: J. R. Faleiro)

Economic impact

Farmers of the arid regions of the world find it increasingly difficult to farm due to several inter-related factors including desertification, combined with land degradation, biodiversity loss, water shortage and fossil fuel shortage. In this context, date palm is very useful, as it has the inherent ability to withstand adverse climate changes, provide a micro-climate in the desert for farmers to grow multiple crops. Dates are utilized as fruit, or in beverages for their sweet taste, and the leaves are harvested for fibers. Correspondingly, animals utilize these trees as shelters and their respective fruit as a source of food (Howard and Giblin-Davis 2008).

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).

CURRENT METHODS USED TO CONTROL *R. FERRUGINEUS*

As the cultivation of date palm has increased in the recent years several new plantations have emerged that are less than 20 years old and susceptible to attack by *R. ferrugineus*. It is estimated that over 50% 0f the date palms in the Middle-East and North Africa are in this age group (< 20 years) (Faleiro et al., 2012; FAOstat 2013). Several methods to control this invasive species have been developed and are currently used to tackle the menace of *R. ferrugineus* in date palm.

In date palm, *R. ferrugineus* has been managed in several countries, using a food baited-pheromone (ferrugineol) trap based IPM strategy comprising of locating and eliminating hidden breeding sites including neglected and closed gardens, maintaining crop and field sanitation, pest surveillance based on periodic field surveys for detecting infestations and also through pheromone traps (monitors), mass trapping of adults in endemic pockets, checking palms to detect infestations, preventive and curative chemical treatments, eradicating severely infested palms, implementing quarantine measures and training and education (Abraham et al., 1998; Faleiro 2006). This article presents an overview of the major *R. ferrugineus*-IPM strategy with case studies in combating the pest in date palm. We also present an insight on the potential of biological control and the use of quarantine regimes to combat *R. ferrugineus* in date palm.

Following is a review of potential early detection techniques and major control tactics used to control *R. ferrugineus* in date palm.

Early detection of *R. ferrugineus* infested date palms

Inspecting date palms in the susceptible age group to detect infested palms in the early stage of attack is vital for the success of any *R. ferrugineus*-IPM programme. Following is an overview of the *R. ferrugineus* infestation detection techniques.

Visual detection

Currently *R. ferrugineus* infested date palms are detected in the field through visual observation of one or more of the above mentioned symptoms of damage. In Al-Hassa, Saudi Arabia trained engineers have been able to detect *R. ferrugineus* infested date palms by recognizing the symptoms of damage associated with *R. ferrugineus* attack in date palm. It has been seen that monthly inspection of severely infested date plantations could successfully maintain infestation levels below the 1% threshold (Al-Shawaf et al., 2012). This is due to the fact that infestations are detected before adult emergence, which takes around 45 days from egg laying to adult emergence, emphasizing the importance of regular inspection of date palms in the susceptible age group to detect infestation and curtail build-up of the pest in the field. However, visual inspection of palms to locate infestations is laborious and time consuming, but together with pheromone trapping is a key component of the *R. ferrugineus* -IPM strategy. Pheromone trap capture data is vital to identify hot spots and judiciously use the inspection teams where most required. In this context, Geographical Information System (GIS) based temporal spread sheets could be developed periodically to ascertain the activity and spread of adult weevils based on the captures in pheromone traps (Massoud et al., 2012).

Bioacoustic detection

Early detection of symptoms focused on picking up the gnawing sound produced by feeding larvae in coconut and date palm (Abraham et al., 1966; Soroker et al., 2004). When a large number of large larvae reside and feed inside palm tissue, then larval sounds due to locomotion and feeding can be even detected with a trained ear. The problem is at early infestation stages when the generated sound is too low to distinguish from the background noise (Soroker et al., 2013). Typically *R. ferrugineus* larval sounds are produced as bursts interspersed by longer, quiet intervals (Mankin et al., 2008). Potamitis et al. (2009) obtained significantly high real-field recordings of *R. ferrugineus*, offering reliable representation of both the acoustic emissions due to the pest and interference from the environment. The major flaws of acoustic technique are in the ambient interference with the low energy emitted by younger larvae, and the need to perform the detection on each tree individually (Soroker et al., 2013). Acoustic technology has potential to enable early detection, but the short, high-frequency sound impulses produced by *R. ferrugineus* larvae can be difficult to distinguish from certain similar sounds produced by other insects or small animals, or by wind-induced tapping noises (Mankin 2011).

Chemical detection

Detecting the chemical signatures emitted by an *R. ferrugineus* infested date palm has been studied as a possible early detection tool. In this context Nakash et al., 2000 confirmed the ability of Golden Retriever dogs to successfully sniff and detect the oozing secretion collected from *R. ferrugineus* infested date palms but the ability of trained dogs to detect the infested palm *in situ* was not proven (Soroker et al., 2013). According to Soroker et al. (2013) using dogs to detect *R. ferrugineus* infested date palms is possible however their use in vast plantations could be restricted particularly during the summer when the ambient temperature is high. Dog-assisted detection could suit well for palm inspection at nurseries, ports of entry and/or quarantine facilities (Soroker et al., 2013). Electronic gas sensors have been used to detect volatile emitted by plants infested by insects. Unfortunately, these sensors are also highly sensitive to the presence of other different compounds such as alcohols, ketones, fatty acids and esters (Magan, 2001) and more studies need to be carried out to develop sensors that can accurately detect chemical signatures of *R. ferrugineus* infested palms.

Thermal imaging detection

Infrared cameras have been used to detect temperature increase in infested palms. A review by Soroker et al. (2013), on recent technological advances in remote thermal images offer the potential to acquire spatial information on surface temperature, and thus facilitate the mapping of canopy temperature variability over large areas. This technique needs further testing and refining to detect *R. ferrugineus* infested palms in the early stage of attack. Larval feeding inside the trunk generates fermented palm tissue resulting in enhanced temperature levels within the infested palm. Recently, El-Faki et al. (2015) provided valuable baseline information on temperature profiles of *R. ferrugineus* infested date palms for developing a real-time sensor fusion system for a nondestructive early detection of insect infestation.

In general, a reliable and easy to handle early detection gadgets that can detect *R. ferrugineus* infested palms in the early stage of attack is the need of the hour for effectively combating the menace of *R. ferrugineus* in date palm. Visual detection of infested date palms through manual inspections will be the only way of locating *R. ferrugineus* infested date palms in the field until reliable and easy to use infestation detection gadgets are developed and deployed in the field.

Host plant resistance, phyto-sanitation and agro-techniques

Palm and field sanitation is important for successfully managing *R. ferrugineus* in date plantations (Abraham et al., 1998; Al-Ajlan 2008) and is closely related agro-techniques associated with date palm production including varietal preference, in-groove humidity that is influenced by palm density (spacing) and irrigation, pruning of fronds and removal of off-shoots. Naturally occurring defense mechanisms against *R. ferrugineus* have not been fully understood and therefore not exploited to manage this lethal pest of palms. As regards varietal preference, studies have shown that date palm cultivars with high sugar content enhance the growth and development, while cultivars with high calcium content with hard tissue inhibits the growth and development of *R. ferrugineus* (Farazmand 2002; Faleiro 2006; Al-Ayedh 2008). Recent reports based on oviposition preference and controlled olfactometer studies showed that the popular date palm cultivar Khlas was highly preferred by *R. ferrugineus* (Faleiro et al., 2014). Gene silencing or RNA interference (RNAi) a recently discovered regulatory and defense mechanism in plants, animals and other organisms, has great potential to control disease and insect pests of date palm including *R. ferrugineus* and provides an entirely new and unique path to develop resistant plant varieties (Niblett and Bailey, 2012).

Inspection of 393 date plantations in 234ha in the Al-Hassa date palm oasis of Saudi Arabia during 2012 by Sallam et al. (2012) to record infestations and other data, revealed that nearly 90% of the infestations occurred on the palm trunk between 0-100 cm from the ground. Occasionally *R. ferrugineus* infestation in date palm occurs in the crown particularly where weevil activity is high. The study by Sallam et al. (2012) also revealed that maximum infestations (36%) were recorded in the age group of 6 to 10 years and is in agreement with previous reports (Abraham et al., 1998). Further, date palms without any off shoots recorded the highest infestation (79%), indicating that upon removal of offshoots the palm is exposed to attack by *R. ferrugineus* especially when the fronds are pruned warranting the need to protect fresh injuries on the palm by application of insecticide as proposed by Abraham et al., 1998. At the same time it is pertinent to mention that inspection of palms to detect infestations becomes difficult in palms with several offshoots. Sallam et al. (2012) also found that close spacing of palms at planting and open flood irrigation favours increased attack by *R. ferrugineus* probably due to enhanced humidity in plantations resulting from these practices and was in agreement with the findings of Aldryhim and Khalil (2003) and Aldryhim and Bukiri (2003) who reported that enhanced soil moisture and flood irrigation provides temporary harborage to adults and increases the possibility of *R. ferrugineus* infestation in date palm.

3.3 Semiochemicals and *R. ferrugineus* control

Insect pheromones are widely used in sustainable insect management programmes that help curtail the use of harmful insecticides. Subsequent to the synthesis formulation and availability of the male produced aggregation pheromone 4-methyl-5-nonanol (Ferrugineol) (Hallet et al., 1993), *R. ferrugineus* pheromone traps have been widely used to monitor weevil activity and mass trap the pest in endemic areas (Abbas et al., 2006; Faleiro 2006). A related ketone (4-methyl-5-nonanone) increased weevil captures by 65% (Abozuhairah et al., 1996). Reports from several countries indicate that the captures are female dominant (Hallett et al., 1999, El-Gahry 1996; Al-Saoud 2011), which is good from the control point of view as it is the female weevils that lay eggs that initiate infestations. The four-window 5L bucket trap with a rough outer surface that was first fabricated and used in Saudi Arabia (Faleiro et al., 1998) is the widely adopted trap design. In Spain the black dome shaped trap is also used to capture RPW adults (Fig. 2).

Dark trap colours (red) have been reported to capture significantly more weevils (Abuagla and Al-Deeb 2012, Al-Saoud et al., 2010; Al-Saoud 2013). The pheromone lure (ferruginol) is known to act synergistically with food bait to enhance weevil captures. Dates (250g) in 1L water is known

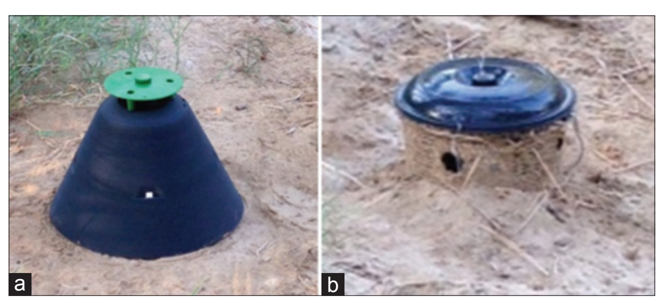

Fig 2. The dome shaped (Picusan™ (a)) and four window bucket trap (b) (Photo: J. R. Faleiro)

to be the best food bait for used in *R. ferrugineus* pheromone traps (Faleiro 2006). Furthermore, several reports suggest that incorporation of ethyl acetate in *R. ferrugineus* trap enhances weevil captures (Oehlschlager 1998; Sebay 2003; Al-Shagag et al., 2008; Al-Saoud 2013). Addition of non-repellent (odourless) insecticide in the traps prevents escapes of captured weevils (Faleiro 2006).Traps are set in the field (ground) by burying the base of the trap in the ground. *R. ferruginues* adults fly to the trap area, land on a surface and then crawl into the trap. Setting *R. ferrugineus* traps on young palms could potentially endanger these palms and expose them to oviposition by female weevils arriving to the trap (Faleiro 2006). Setting traps under shade ensures better field longevity of the lure (Faleiro, et al 1999). *R. ferrugineus* pheromone traps need to be serviced at least once in two weeks when the food bait and water has to be renewed. A three month field trial in date plantations of Saudi Arabia using a bait-free method to 'attract and kill' *R. ferrugineus* adults showed that the trapping efficiency of this method was comparable to the traditional food baited-pheromone traps, (El-Shafie et al., 2011). However, further field tests are required to optimize the number of killing points and also to ascertain the extent of palm protection provided by this technique. Depending on the lure used and exposure of the trap to sunlight, the pheromone lure needs to be periodically (1-3months) replaced with a new lure. Mass trapping programmes initially use 1trap/ha, however in plantations with high weevil activity and >1% infestation 4-10 traps/ha effectively captures emerging adult weevils (Faleiro et al., 2011, Soroker, et al., 2005). A new dimension to the use of semiochemicals for the sustainable management of *R. ferrugineus* in date palm could look into the possibility of identifying and deploying insect repellents with pheromones in an area-wide programme involving a push-pull strategy. In this context it is pertinent to mention the identification of α-pinene, singly or in combination with methyl salicylate or menthone as a potential *R. ferrugineus* repellent (Guarino et al., 2013). However, further studies are necessary to quantify the extent of palm protection this repellent could provide.

Chemical control and eradication

Insecticide treatments of date plantations in endemic hot spots by taking up preventive spray/shower applications are practiced to restrict the spread of *R. ferrugineus*. Protecting fresh injuries from invading female weevils through insecticide application (Fig. 3) to prevent egg laying has been recommended in the past (Abraham et al., 1998). Curative insecticide treatments of palms in the early stage of attack through stem injection technique are known to cure such palms. Initially organophosphate (trichlorphon) and carbamate (carbaryl) based insecticides were used both in preventive and curative applications based on experiences on coconut in South Asia (Abraham et al., 1975; Kurian and Mathen, 1971; Faleiro 2006).

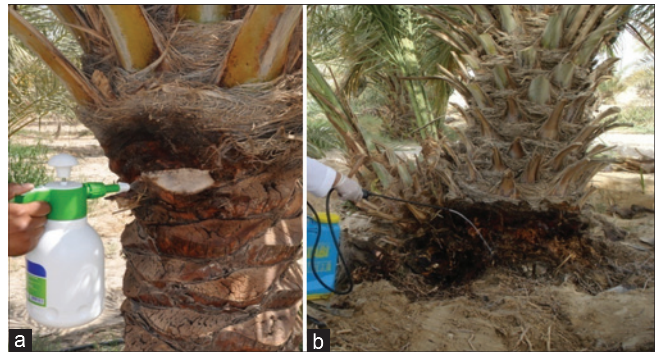

Fig 3. Protect fresh injuries on the palm with insecticide immediately after frond shaving (a) and offshoot removal (b) (Photo: J.R. Faleiro)

More recently however, new generation insecticides belonging to the neonicotinoid (imidacloprid) and phenylpyrazole (fipronil) groups are used in prophylactic and curative applications against *R. ferrugineus* in date palm (Kaakeh 2006; Al-Shawaf et al., 2010). Currently stem injection of infested date palms is practiced in some countries using pressure injectors. However, utmost care should be taken to see that the pressure does not exceed 1 bar to prevent permanent tissue damage when insecticide is forced into the palm at higher pressure. Such treatments need to be taken up under supervision of trained staff.

Palms in the late stage of attack with extensive tunneling and tissue damage often harbor overlapping stages of the pest and have to be eradicated by shredding. At current levels of detection around 20% of the infested date palms are eradicated (Al-Shawaf et al., 2012). Eradication of *R. ferrugineus*-infested date palms could generate vast material for compost making. Eradication by burning is not desirable as often hidden stages of the pest are deep inside the palm tissue where the fire and heat generated may not be lethal.

A summary of case studies involving pheromone based IPM against *R. ferrugineus* in different date producing countries of the Middle East is presented in Table 2.

Potential of biological control in *R. ferrugineus* management

A recent review on the natural enemies of *Rhynchophorus* palm weevils, with focus on *R. ferrugineus*, more than 50 natural enemies including viruses, bacteria, fungi, nematodes, yeast, mites, insects and vertebrates have been reported to attack the *Rhynchophorus* species. Among the potential organisms, fungi were noteworthy to be considered for inclusion in integrated pest management programs *R. ferrugineus* (Mazza et al., 2014). Previously several biological control agents have been reported against *R. ferrugineus* (Murphy and Briscoe 1999; Faleiro 2006, Al-Ajlan 2008) of which Entomo-Pathogenic Fungi (EPF)

Table 2: Impact of area-wide management of *R. ferrugineus* in date plantations of different countries in the Middle-East

Sr. No.	Country	Highlights	Reference
1	United Arab Emirates	A major study carried out in the UAE between 1994 and 1998 carried out in 1,466 farms initially containing 349,342 palms with an average infestation rate of 1.9%, infestations were found to decrease in 1998 by 64% from 1997 levels in the farms that received insecticide treatments and pheromone traps, as compared to a decrease of 36% in the farms that received only chemical treatment	El-Ezaby et al., 1998; Oehlschlager, 2006
2	Saudi Arabia	In Al-Qatif date palm oasis (in 4,000 ha) weevil captures reduced from 4.12 weevils per trap per week in 1994 to 2.02 weevils per trap per week in 1997 Infestation levels in the date palm plantations containing traps decreased from 6.6% in 1993 to 2.5% in 1997	Vidyasagar et al., 2000
3	Saudi Arabia	RPW was effectively monitored with traps in pest free areas at a density of one trap per 100 ha and successfully controlled (in 4000 ha) between 1994-1997 by mass trapping adult weevils at 1 trap/1.5 ha	Abraham et al., 2000
4	United Arab Emirates	In another report from UAE six date plantations in which pheromone traps captured the highest numbers of weevils exhibited the greatest reduction of infestation. In this study the average annual reduction in infestation over all six farms was 71%	Kaakeh et al., 2001; Oehlschlager 2006
5	Sultanate of Oman	In Oman pheromone trapping of *R. ferrugineus* in date plantations is credited with reduction in eradications from 24% in 1998 to 3% in 2003	Al- Khatri 2004
6	Israel	In Israel mass trapping of *R. ferrugineus* in 450 ha of date plantations along with other RPW-IPM tactics between 1999 and 2001 resulted in the decrease in the number of weevils trapped by the end of 2001, with no infestation being found since 2002	Soroker et al., 2005
7	Saudi Arabia	Area-wide management of the pheromone based *R. ferrugineus* -RPW control programme in Al-Hassa was validated in 15 operational areas comprising of more than 4000ha (>35% of the area with over 1.08 million palms) for six months from April to September, 2011 based on mean monthly values for weevil captures in food-baited pheromone traps, infestation levels and eradication of severely infested palms Results revealed that mean monthly weevil captures were significantly different in the 15 operational areas sampled, but were statistically at par in the three major zones (centre, north and east) of the oasis while infestation levels in the operational areas varied significantly and were found to be well below the 1% action threshold in the east of the oasis, nearing 1% in the centre while being well above the threshold (1% infestation) in the north. In general, the study showed that while the pheromone based IPM strategy adopted had the desired impact in the east, the strategy needed minor adjustments in the centre but called for major reinforcement in the north of the oasis	Al-Shawaf et al., 2012
8	Saudi Arabia	Data spanning over a six year period (2007 to 2012) from Al Ahsa, Saudi Arabia in a 1,104 ha date producing region of the Al -Hassadate palm oasis involving a 10 fold increase in the number of pheromone traps that was initiated in October, 2009 revealed that total number of *R. ferrugineus* adults captured in 2012 declined by 86% when compared to total captures for 2010.Furthermore, over the same time period, insecticide application and palm eradication rates dropped by 91% and 89%, respectively	Hoddle et al., 2013

and Entomo-Pathogenic Nematodes (EPN) are promising (Hanounik 1998;Salama et al.,2001; Abbas et al., 2001; Gindin et al.,2006; Manachini et al., 2013). However in date palm, deployment of these agents in the field has not been encouraging probably due to the extreme climatic conditions prevailing in the arid regions of the world where date palm is cultivated and also the hidden nature of the pest making it difficult for EPNs and EPFs to survive the harsh climatic condition and inability to reach the pest life stages deep into the palm. In Spain however on the canary island palm, application of the EPN *Steinernema carpocapsae* (Weiser) in semi-field trials proved effective against *R. ferrugineus* with efficacies of up to 98% and 80%, in both preventive and curative assays, respectively (Llácer et al., 2009). Manachini et al. (2013) reported a positive trend of *R. ferrugineus* with dosage and duration of exposure to *S. carpocapsae*. With regard to EPF, Dembilio et al., 2010 recorded up to 86% adult mortality under field conditions in Spain of with a Spanish strain of *Beauveria bassiana*. Recently Hajjar, 2015 through laboratory and semi-field cage studies showed the possibility of infecting R. *ferrugineus* adults with *B. bassiana* using pheromone traps.

Identifying and testing heat tolerant strains of EPFs and EPNs suitable for deployment in date plantations of the Middle-East would go a long way in reinforcing the pheromone based *R. ferrugineus*-IPM strategy currently employed in area wide programmes against this lethal pest.

Importance of plant quarantine in *R. ferrugineus* management

Abraham et al. (1998) highlighted the importance of implementing strict quarantine regimes as a component of the *R. ferrugineus* strategy. Transport of date palm offshoots for date farming and bigger date palms for landscape gardening often results 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* (Fig. 4). Experiences from the Gulf region in the Middle-East and the Mediterranean countries have shown that *R. ferrugineus* 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.

However, 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. 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.

CONCLUSION

Undoubtedly *R. ferrugineus* is among the world's most invasive pest species of palms that has rapidly expanded its geographic range during the last three decades especially after it gained foot hold on date palm in the Middle-East during the mid-1990s. Adopting *R. ferrugineus* mitigating date palm agro-techniques from varietal selection, palm density in the field, irrigation method to regulate in-groove humidity, identifying and eliminating hidden breeding sites are essential. Besides, trapping adult weevils using food baited pheromone traps to monitor and mass trap adult weevils, inspection of palms to detect infestations before adults emerge is crucial to ensure success of the *R. ferrugineus*-IPM programme. The importance of regular inspection of date palm grooves in the susceptible age of less than 20 years to manually and visually detect infestation has been overlooked by pest managers and needs to be emphasised as an important component of the current *R. ferrugineus*-IPM strategy. In this context, developing a reliable and easy to use detection gadget that can detect *R. ferrugineus* infested palms in the early stage of attack is the need of the hour for effectively combating the menace of *R. ferrugineus* in date palm. Preventive and curative insecticide applications have to be judicious and need based. Furthermore, implementing strict quarantine regimes to regulate the palm nursery/planting industry is essential to reinforce the *R. ferrugineus* -IPM programme, prevent spread of this pest through planting material and sustain control levels. Developing new semiochemical based control strategies involving "attract & kill" and "push & pull" techniques could substantially strengthen the ongoing pheromone based IPM programme against *R. ferrugineus* in date palm. At a molecular level, gene scilencing or RNA interference (RNAi) technology needs to be developed and exploited to augment the current semiochemical based strategy against *R. ferrugineus* in date palm. Regular training of the staff involved in the control programme and participation of date palm farmers in the area-wide IPM strategy would ensure success in controlling this lethal pest of date palm.

Fig 4. Transportation of date palms for ornamental gardening: A potential RPW quarantine risk (Photo: J. R. Faleiro)

Author contribution

All authors contributed equally in this article.

REFERENCES

Abbas, M. S. T., M. M. E. Saleh and A. M. Akil. 2001. Laboratory and field evaluation of the pathogenicity of entomopathogenic nematodes to the red palm weevil, *Rhynchophorus ferrugineus* (Oliv.) (Coleoptera: Curculionidae). J. Pest Sci. 74: 167-168.

Abbas, M. S. T., S. B. Hanounik, A. S. Shahdad and S. A. Al-Bagham. 2006. Aggregation pheromone traps, a major component of IPM strategy for the red palm weevil, *Rhynchophorus ferrugineus,* in date palms (Coleoptera: Curculionidae). J. Pest Sci. 79: 69-73.

Abuagla, A. M. and M. A. Al-Deeb. 2012. Effect of bait quantity and trap color on the trapping efficacy of the pheromone trap for the red palm weevil *Rhynchophorus ferrugineus*. J. Insect Sci. 12: 120. Available from: http://www.insectscience.org/12.120. [Last accessed on 2013 apr 23]

Abraham, V. A., M. A. Al-Shuaibi, J. R. Faleiro, R. A. Abozuhairah and P. S. P. V. Vidyasagar. 1998. An integrated management approach for red palm weevil, *Rhynchophorus ferrugineus* Oliv., a key pest of date palm in the Middle East. Agric. Sci. 3: 77-83.

Abraham, V. A. and C. Kurian. 1975. An integrated approach to the control *Rhynchophorus ferrugineus* F. the red weevil of coconut palm. Proceedings, 4th Session of the FAO Technical Working Party on Coconut Production, Protection and Processing, 14-25 September, Kingston, Jamaica.

Abraham, V. A., J. R. Faleiro, M. A. Al-Shuaibi and S. Al Abdan. 2001. Status of pheromone trap captured female red palm weevils from date gardens in Saudi Arabia. J. Trop. Agric. 39: 197-199.

Abraham, V. A., J. R Faleiro, M. A. Al-Shuaibi and Prem Kumar, T. 2000. A strategy to manage red palm weevil *Rhynchophorus ferrugineus* Oliv. On Date Palm Phoenix dactylifera L.– Its successful implementation in Al-Hassa, Kingdom of Saudi Arabia. Pestology. 24(12): 23-30.

Abraham, V. A., K. Mathen and C. Kurian. 1966. Aids to detect red palm weevil infestation in coconut palm. Coconut Bull. 20: 148-152.

Abozuhairah, R. A., P. S. P. V. Vidyasagar and V. A. Abraham. 1996. Integrated management of red palm weevil, *Rhynchophorus ferrugineus* F. in date palm plantations of the Kingdom of Saudi Arabia. XX International Congress of Entomology, Florence, Italy, August 25-31, 1996. Tropical Entomology (Sect.) Paper 17-033.

Al-Shagag, A., A. H. Al-Abbad, A. M. Al-Dandan, A. Ben Abdallah and J. R. Faleiro. 2008. Enhancing trapping efficiency of red palm weevil pheromone traps with ethyl acetate. Indian J. Plant Prot. 36: 310-311.

Al-Shawaf Abdul Moneim, A., A. A. Al-Shagagh, M. M. Al-Bakshi, S. A. Al-Saroj, S. M. Al-Badr, A. M. Al-Dandan and A. Ben Abdallah. 2010. Toxicity of some insecticides against red palm weevil *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae). Indian J. Plant Prot. 38(1): 13-16.

Al-Shawaf, A. M., S. Al-Abdan, A. H. Al-Abbad, A. Ben Abdallah and J. R. Faleiro. 2012.Validating area-wide management of *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae) in date plantation of Al-Hassa. Indian J. Plant Prot. 40(4): 255-259.

Al-Shawaf, A. M., A. Al-Shagag, M. Al-Bagshi, S. Al-Saroj, S. Al-Bather, A. M. Al-Dandan, A. Ben Abdallah and J. R. Faleiro. 2013. A quarantine protocol against red palm weevil *Rhynchophorus ferrugineus* (Olivier) (Coleptera: Curculiondae) in date palm. J. Plant Prot. Res. 53(4): 409-415.

Al-Ajlan, A. M. 2008. Red palm weevil, *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae). In: Capinera, J. L., (Ed.), Encyclopedia of Entomology, Vol. 18. Springer Science, New York, Pp. 3127-3130.

Al-Ayedh, H. 2008. Evaluation of date palm cultivars for rearing the red date palm weevil, *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae). Florida Entomol. 91: 353-358.

Al- Khatri, S. A. 2004. Date palm pests and their control. Proceedings, Date Palm Regional Workshop on Ecosystem-Based IPM for Date Palm in Gulf Countries, 28-30 March, Al-Ain, UAE, Pp. 84-88.

Al-Farsi, M., C. Alasalvar, A. Morris, M. Barron and F. Shahidi. 2005. Compositional and sensory characteristics of three native sun-dried date (*Phoenix dactylifera* L) varieties grown in Oman. J. Agric. Food Chem. 53: 7586-7591.

Al-Saoud, A. H., M. A. Al-Deeb and A. K. Murchie. 2010. Effect of color on the trapping effectiveness of red palm weevil pheromone traps. J. Entomol. 7(1): 54-59.

Al-Saoud, A. H. 2013. Effect of ethyl acetate and trap colour onweevil captures in red palm weevil *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae) pheromone traps. Int. J. Trop. Insect Sci. 33(3): 202-206.

Aldryhim, Y. and S. Al-Bukiri. 2003. Effect of irrigation on within – Grove distribution of red palm weevil *Rhynchophorus ferrugineus*. Agric. Marine Sci. 8: 47-49.

Aldryhim, Y. and A. Khalil. 2003. Effect of humidity and soil type on survival and behaviour of red palm weevil *Rhynchophorus ferrugineus* (Oliv.) adults. Agric. Marine Sci. 8: 87-90.

Anonymous. 2013. Save Algarve Palms. Available from: http://www.savealgarvepalms.com/en/weevil-facts/host-palm-trees. [Last accessed on 2013 Mar 24].

Avand Faghih, A. 1996. The biology of red palm weevil, *Rhynchophorus ferrugineus* Oliv. (Coleoptera: Curculionidae) in Saravan region (Sistan and Balouchistan Province, Iran). Appl. Entomol. Phytopath. 63: 16-18.

Ávalos, J. A., A. Martı´-Campoy and A. Soto. 2014. Study of the flying ability of *Rhynchophorus ferrugineus* (Coleoptera:Dryopthoridae) adults using a computerized flight mill. Bull. Entomol. Res. 104: 462-470.

Baloch, M. K., S. A. Saleem, K. Ahmad, A. K. Baloch and W. A. Baloch. 2006. Impact of controlled atmosphere on the stability of Dhakki dates. Swiss Soc. Food Sci. Technol. 39: 671-676.

Bertone, C., P. S. Michalak and A. Roda. 2010. New pest response Guidelines, Red Palm Weevil (*Rhynchophorus ferrugineus)*. Available from: http://www.aphis.usda.gov/import_export/plants/manuals/emergency/downloads/nprg-redpalmweevil.pdf. [Last accessed on 2010 Nov 13].

Brand, E. 1917. Coconut red weevil. Some facts and fallacies. Trop. Agric. Mag. Ceylon Agric. Soc. 49(1): 22-24.

CDFA. 2010. Red palm weevil, worst known pest of palm trees detected in Laguna Beach. California Department of Food and Agriculture (CDFA) Press Release # 10-061.

Dembilio, O., E. Quesada-Moraga, C. Santiago-Alvarez and J. A. Jacas. 2010. Biocontrol potential of an indigenous strain of the entomopathogenic fungus *Beauveria bassiana* (Ascomycota; Hypocreales) against the red palm weevil, *Rhynchophorusferrugineus* (Coleoptera: Curculionidae). J. Invert. Path. 104: 214-221.

Dembilio, O. and J. A. Jacas. 2012. Bio-ecology and integrated management of the red palmweevil, *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae), in the region of Valencia (Spain). Hellenic Plant Prot. J. 5: 1-12.

El-Garhy, M. E. 1996. Field evaluation of the aggregation pheromone of *Rhynchophorus ferrugineus* in Egypt. Brighton Crop Protection Conference, Pests and Disease, 3: 18-21.

El-Ezaby, F.A.A., O. Khalifa and A. El-Assal. 1998. Integrated pest management for the control of red palm weevil, *Rhynchphorus ferrugineus* Oliv in the United Arab Emirates, Eastern Region, Al Ain. Proceedings of 1st International Conference on Date Palms, Mar. 8-10, UAE: University, Al-Ain, UAE. p269-281. Available from: http://www.pubhort.org/datepalm/datepalm1/datepalm1_23.pdf.

El-Faki, M. S., H. A. F.El-Shafie and M. B. R. Al-Hajhoj. 2015. Potentials for early detection of red palm weevil (Coleoptera: Curculionidae)-infested date palm (Arecaceae) using temperature differentials. Canadian Entomol. doi:10.4039/tce.2015.51

El-Hadrami, A. and J. M. Al-Khayri. 2012. Socioeconomic and traditional importance of date palm. Emirates J. Food Agric. 24(5): 371-385.

El-Sabea, A. M. R., J. R. Faleiro and M. M. Abo El Saad. 2009.The threat of red palm weevil *Rhynchophorus ferrugineus* to date plantations of the Gulf region of the Middle East: an economic perspective. Outlook on Pest Manag. 20: 131-134.

El-Shafie, H. A. F., J. R. Faleiro, A. H. Al-Abbad, L. Stoltman and A. Mafra-Neto. 2011. Bait-free attract and kill technology (Hook™ RPW) to suppress red palm weevil, *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae) in date palm. Florida Entomol. 9: 774-778.

El-Shafie, H. A. F. 2012. Review: List of arthropod pests and their natural enemies identified worldwide on date palm, *Phoenix dactylifera* L. Agric. Biol. J. North Am. Available from: http://www.doi:10.5251/abjana.20123.12516.524.

EPPO. 2008. Data sheets on quarantine pests. *Rhynchophorus ferrugineus*. EPPO Bull. 38: 55-59.

Faleiro, J. R., V. A. Abraham and M. A. Al-Shuaibi. 1998. Role of pheromone trapping in the management of red palm weevil. Indian Coc. J. 29(5): 1-3.

Faleiro, J. R., M. Al-Shuaibi, V. A. Abraham and T. Prem Kumar. 1999. A technique to assess the longevity of the palm weevil pheromone (Ferrolure) under different conditions in Saudi Arabia. Agric. Sci. 4(1): 5-9.

Faleiro, J. R., J. Ashok Kumar and P. A. Rangnekar. 2002. Spatial distribution of red palm weevil *Rhynchophorus ferrugineus* Oliv. (Coleoptera: Curculionidae) in coconut plantations. Crop Prot. 21: 171-176.

Faleiro, J. R., P. A. Rangnekar and V. R. Satarkar. 2003. Age and fecundity of female red palm weevil *Rhynchophorus ferrugineus* (Olivier) (Coleoptera*:* Rhynchophoridae) captured by pheromone traps in coconut plantations of India. Crop Prot. 22: 999-1002.

Faleiro, J. R. 2006. A review of the issues and management of the red palm weevil *Rhynchophorus ferrugineus* (Coleoptera: Rhynchophoridae) in coconut and date palm during the last one hundred years. Int. J. Trop. Insect Sci. 26: 135-154.

Faleiro, J. R., M. A. El-Saad and A. H. Al-Abbad. 2011. Pheromone trap density to mass trap *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae/Rhynchophoridae/Dryophoridae) in date plantations of Saudi Arabia. Int. J. Trop. Insect Sci. 31: 75-77.

Faleiro, J. R., A. Ben Abdullah, M. El-Bellaj, A. M. Al Ajlan and A. Oihabi. 2012. Threat of red palm weevil, *Rhynchophorus ferrugineus* (Olivier) to date palm plantations in North Africa. Arab J. Plant Prot. 30: 274-280.

Faleiro, J. R., H. A. F. El-Shafie, A. M. Ajlan and A. A. Sallam. 2014. Screening date palm cultivars for resistance to red palm weevil *Rhynchophorus ferrugineus* (Coleptera: Curculiondae). Florida Entomol. 97(4): 1529-1536.

FAOSTAT. 2013. Food and Agricultural Commodities Production. Available from: http://www.faostat3.fao.org/download/Q/QC/E. [Last accessed on 2015 Oct 23].

Farazmand, H. 2002. Investigation on the reasons of food preference of red palm weevil, *Rhynchophorus ferrugineus* Oliv. Appl. Entomol. Phytopath. 70: 11-12.

Giblin-Davis, R. M., J. R. Faleiro, J. A. Jacas, J. E. Peña and P. S. P. V. Vidyasagar. 2013. Coleoptera: Biology and management of the red palm weevil, *Rhynchophorus ferrugineus*. In: Peña, J. E., (Ed.), Potential Invasive Pests of Agricultural Crop Species, CABI Wallingford, UK, Pp. 1-34.

Gindin, G., S. Levski, I. Glazer and V. Soroker. 2006. Evaluation of the entomopathogenic fungi *Metarhizium anisopliae* and *Beauveria bassiana* against the red palm weevil *Rhynchophorus ferrugineus*. Phytoparasitica. 34(4): 370-379.

Guarino S., E. Peri, P. L. Bue, M. P. Germanà, S. Colazza, L. Anshelevich, U. Ravid and V. Soroker. 2013. Assessment of synthetic chemicals for disruption of *Rhynchophorus ferrugineus* response to attractant-baited traps in an urban environment. Phytoparasitica. 41: 79-88.

Hajjar, M. J., A. M. Ajlan and M. H. Al-Ahmad. 2015. New approach of *Beauveria bassiana* to control the red palm weevil (Coleoptera: Curculionidae) by trapping technique. J. Econ. Entomol. 108(2): 425-432.

Hallett, R. H., G. Gries, R. Gries, J. H. Borden, E. Czyzewska, A. C. Oehlschlager, H. D. Pierce, Jr, N. P. D. Angerilli and A. Rauf. 1993. Aggregation pheromones of two Asian palm weevils *Rhynchophorus ferrugineus* and *R. vulneratus.* Naturwissenschaften. 80: 328-331.

Hallett, R. H., A. C. Oehlschlager and J. H. Borden. 1999. Pheromone trapping protocols for the Asian palm weevil, *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae). Int. J. Pest Manag. 45: 231-237.

Hanounik, S. B. 1998. Steinernematids and heterorbhabditids as biological control agents for the red palm weevil (*Rhynchophorus ferrugineus* Olivier). Agric. Sci. 3: 95-102.

Hoddle, M. S., A. H. Al-Abbad, H. A. F. El-Shafie, J. R. Faleiro, A. A. Sallam and C. D. Hoddle. 2013. Assessing the impact of pheromone trapping, pesticide applications, and eradication of infested date palms for *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae) management in Al Ghowaybah, Saudi Arabia. Crop Prot. 53: 152-160.

Hoddle, M. S., C. D. Hoddle, J. R. Faleiro, H. A. F. El-Shafie, D. R. Jeske and A. A. Sallam. 2015. How far can the red palm weevil (Coleoptera: Curculionidae) fly? Computerized flight mill studies with field-captured weevils. J. Econ. Entomol. 108(6): 2599-2609.

Howard, F. W. and R. M. Giblin-davis. 2008. Palm insects. In: Capinera, J.L., (Ed.), Encyclopedia of Entomologist, Vol. 16. Springer Science, New York, Pp. 2721-2726.

Johnson, D. V., J. M. Al-Khayri and S. M. Jain. 2015a. Date production status and prospects in Africa and the Americas. In: J. M., (Eds.), Date Palm Genteic Resources and Utilization. Vol. 1. Ch. 1. Springer Science Springer Science + Business Media, Dorchester, Holland, Pp. 3-18. doi: 10.1007/978-94-017-9694-1.

Johnson, D. V., J. M. Al-Khayri and S. M. Jain. 2015b. Date production status and prospects in Asia and Europe. In: Al-Khayri, J. M., S. M. Jain and D. V. Johnson (Eds.), Date Palm Genteic Resources and Utilization. Vol. 2. Ch. 1. Africa and the Americas. Springer Science + Business Media Dordrecht, Holland. doi: 10.1007/978-94-017-9707-8_1.

Kaakeh, W., F. El-Ezaby, M. M. Abu Al-Nour and A. A. Khamis. 2001. Management of the Red Palm Weevil by a Pheromone/Food-Based Trapping System, Second International Conference. On Date Palms, Al-Ain, UAE, March 25-27. Pp. 325-343. Available from: http://www.pubhort.org/datepalm2/datepalm2-38.pdf. Accessed on 15 April, 2015

Kaakeh, W. 2006. Toxicity of imidacloprid to developmental stages of *Rhynchophorus ferrugineus* (Curculionidae: Coleoptera): Laboratory and field tests. Crop Prot. 25: 432-439.

Kehat, M. 1999. Threat to date palms in Israel, Jordan, and the Palestinian Authority by the red palm weevil, *Rhynchophorus ferrugineus.* Phytoparasitica. 27(3): 241-242.

Kurian, C. and Mathen, K. 1971. Red palm weevil - Hidden enemy of coconut palm. Indian Farming. 21(1): 29-31.

Lefroy, H. M. 1906. The More Important Insects Injurious to Indian Agriculture. Government Press, Calcutta, India.

Llácer, E., M. M. Martínez de Altube and J. A. Jacas. 2009. Evaluation of the efficacy of S*teinernema carpocapsae* in a chitosan formulation against the red palm weevil, *Rhynchophorus ferrugineus,* in *Phoenix canariensis*. Biol. Control. 54: 559-565.

Magan, D. 2001. Use of electronic nose technology for detection of contamination in food. New Food. 4: 79-81.

Mankin, R. W., A. Mizrach, A. Hetzroni and V. Soroker. 2008. Temporal and spectral features of sounds of wood-boring beetle larvae: Identifiable patterns of activity enable improved discrimination from background noise. Florida Entomol. 91: 241-248.

Mankin R. W. 2011. Recent developments in the use of acoustic sensors and signal processing tools to target early infestations of red palm weevil in agricultural environments. Florida Entomol. 94(4): 761-765.

Manachini, B., D. Schillaci and V. Arizza. 2013. Biological responses to *Rhynchophorus ferrugineus* (Curculionidae: Coleoptera) to *Steinernema carpocapsae* (Nematoda: Steinernematidae) . J. Econ. Entomol. 106(4): 1582-1589.

Massoud, M. A., A. A. Sallam, J. R. Faleiro and S. Al-Abdan. 2012.

Geographic information system-based study to ascertain the spatial and temporal spread of red palm weevil *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae) indate plantations. Int. J. Trop. Insect Sci. 32(2): 108-115.

Mazza, G., V. Francardi, S. Simoni, C. Benvenuti, R. Cervo, J. R. Faleiro, E. Llácer, S. Longo, R. Nannelli, E. Tarasco and P. F. Roversi. 2014. An overview on the natural enemies of *Rhynchophorus* palm weevils, with focus on *R. ferrugineus*. Biol. Control. 77: 83-92.

Murphy, S. T. and B. R. Briscoe. 1999. The red palm weevil as an alien invasive: Biology and prospects for biological control as a component of IPM. Biol. Control. 20: 35-45.

Nakash, J., Y. Osem and M. Kehat. 2000. A suggestion to use doges for detecting red palm weevil (*Rhynchophorus ferrugineus*) infestation in date palms in Israel. Phytoparasitica. 28(2): 153-155.

Niblett, C. L. and A. M. Bailey. 2012. Potential applications of gene silencing or RNA interference (RNAi) to control disease and insect pests of date palm. Emirates J. Food Agric. 24(5): 462-469.

Oehlschlager, A. C. 1998. Trapping of the date palm weevil. Proceeding, FAO conference workshop on date palm weevil (*Rhynchophorus ferrugineus*) and its control, Cairo, Egypt.

Oehlschlager, A. C. 2006. Mass trapping as a strategy for management of *Rhynchophorus* palm weevils, I Jornada Internacional sobre el Picudo Rojo de las Palmeras, Pp. 143-180.

OEPP/EPPO. 2005. Data sheets on quarantine pests *Rhynchophorus palmarus*. OEPP/EPPO Bull. 35: 468-471.

Potamitis,I., T. Ganchev and D. Kontodimas. 2009. On automatic bioacoustics detection of pests: The cases of *Rhynchophorus ferrugineus* and *Sitophilus oryzae*. J. Econ. Entomol. 102(4): 1681-1690.

Rugman-Jones, P. F., C. D. Hoddle, M. S. Hoddle and R. Stouthamer. 2013. The lesser of two weevils: Molecular-genetics of pest palm weevil populations confirm *Rhynchophorus vulneratus* (Panzer 1798) as a valid Species Distinct from *R. ferrugineus* (Olivier 1790), and reveal the global extent of both. PLoS One 8(10): e78379. doi:10.1371/journal.pone.0078379.

Sebay, Y. 2003. Ecological studies on the red palm weevil, *Rhynchophorus ferrugineus* Oliv (Coleoptera: Curculionidae) in Egypt. Egypt. J. Agric. Res. 81: 523-529.

Sallam, A. A., H. A. F. El-Shafie and S. Al-Abdan. 2012. Influence of farming practices on infestation by red palm weevil *Rhynchophorus ferrugineus* (Olivier) in date palm: A case study. Int. Res. J. Agric. Sci. Soil Sci. 2: 370-376.

Salama, H. S. and M. M. Abd-Elgawad. 2001. Isolation of heterorhabditid nematodes from palm tree planted areas and their implications in the red palm weevil control. J. Pest Sci. 74: 43-45.

Salama, H. S., M. S. Foda, and M. A. El-Bendary. 2004.Infection of red palm weevil, *Rhynchophorus ferrugineus* by spore-forming bacilli indigenous to its natural habitat in Egypt. J. Pest Sci. 77: 27-31.

Soroker, V., Y. Nakache, U. Landau, A. Mizrach, A. Hetzroni and D. Gerling. 2004. Utilization of sounding methodology to detect infestation by *Rhynchophorus ferrugineus* on palm offshoots. Phytoparasitica. 32(1): 6-8.

Soroker, V., D. A. Blumberg, M. Haberman, S. Hamburger-Rishard, S. Reneh, L. Talebaev, L. Anshelevich, and A. R. Harari. 2005. Current status of red palm weevil infestation in date palm plantations in Israel. Phytoparasitica. 33(1): 97-106.

Soroker, V., P. Suma, A. La Pergola, Y. Cohen, Y. Cohen, V. Alchanatis, O. Golomb, E. Goldshtein, A. Hetzroni, L. Galazan, D. Kontodimas, C. Pontikakos, M. Zorovoc and M. Brandstetter. 2013. Early detection and monitoring of red palm weevil: Approaches and challenges. AFPP-Palm Pest Mediterranean Conference, Niece, France. 16-18 January, 2013.

Vayalill, P. K. 2002. Antioxidant and antimutagenic properties of aqueous extract of date fruit (*Phoenix dactylifera* L. Arecaceae). J. Agric. Food Chem. 50: 610-617.

Vidyasagar, P. S. P. V., M. Hagi, R. A. Abozuhairah, O. E. Al-Mohanna and A. A. Al-Saihati. 2000. Impact of mass pheromone trapping on red palm weevil adult population and infestation level in date palm gardens of Saudi Arabia. Planter. 76(891): 347-355.

Wattanapongsiri, A. (1966) A revision of the genera *Rhynchophorus* and *Dynamis* (Coleoptera: Cuculionidae). Vol. 1. Department of Agriculture Science Bulletin, Bangkok, Thailand, p. 328.

Zada, A., V. Soroker, M. Harel, J. Nakache, and E. Dunkelblum. 2002. Quantitative GC analysis of secondary alcohols pheromones, determination of the release rate of the red palm weevil, *Rhynchophorus ferrugineus*, pheromone from lures. J. Chem. Ecol. 28: 2279-2286.

Zaid, A., De Wet, P. F., Djerbi, M. and Oihab, A. 2002. Diseases and pests of date palm. In: Zaid, A., (Ed.), Date Palm Cultivation. FAO Plant Production and Protection Paper No. 156, Rev. 1. FAO, Rome.