RED PALM WEEVIL

Rabab A.A. El-Mergawy

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PREFACE

Red palm weevil (RPW), *Rhynchophorus ferrugineus* (Olivier 1790) (Coleoptera: Curculionidae) is an invasive species that attacks several palm species (Arecaceae) causing destructive economic damages (Altwerky 2012; Dembilio and Jacas 2012; Dembilio *et al*. 2009a; El-Sabea *et al*. 2009; EPPO 2008a, 2008b; Faleiro 2006b; Gush 1997; Hussain *et al*. 2013; Malumphy and Moran 2009; Moore 2000; Yin *et al*. 2013; Vidyasagar *et al*. 2000; Zaid 1999). It originated from Southeast Asia and Melanesia (Abraham *et al*. 1975; Ferry and Gomez 2002; Lokma and Alquat 2002; Murphy and Briscoe 1999; Wattanpongsiri 1966), particularly from the northern and western parts of the continental Southeast Asia, Sri Lanka and Pakistan, the Philippines, Vietnam, India and Cambodia (Rugman-Jones *et al*. 2013). It was introduced to the Middle East in the mid 1980's (Bokhari and Abuzuhari 1992; Gomez and Ferry 1999). It was recorded in different localities belonging to Africa, Asia, Caribbean, Europe and the Oceania (El-Mergawy 2011, 2012, 2013).The commercial exchanges of the offshoots among and within different countries facilitated the rapid spread and the extension of the RPW range of expansion (Abraham *et al*. 1998; Murphy and Briscoe 1999). RPW local extension occurred either with the same mechanism or as series of secondary invasion (EL-Mergawy 2011, 2012, 2013). The main goal of RPW management is to protect healthy, and treat infected palm trees.

The principle objectives of the RPW management program are: 1) to avoid the spread of RPW to non-infected areas, 2) to treat the infected palms early before they are completely damaged, and 3) to maintain the infestation level below 1 % in a given treated area (Faleiro 2006b), below eight infested palms in 1 h (100 palms) or below 55 infested palms in 10 h (10000 palms) (Faleiro *et al*. 2010). RPW management program decision depends on the palm economic value (The Alameda 2008), the palm category (Ferry and Gomez 2012), the level of infestation (Pontikakos and Kontodimas 2013; Soroker *et al*. 2013; The Alameda 2008; Vidyasagar and Aldosary 2011), the period of the year (The Alameda 2008), and the size of the area to be managed. According to the appearance of symptoms, the period of treatment divided as follows: 1) May to October- palms with or without symptoms and highly infected palms: the palm trees are treated by nematode (20-30 M / every 45 days) (The Alameda 2008), 2) June to September-palms with or without symptoms and highly infected palms: the palms are treated by the injection of a pesticide (Imidaclopride (1 M/L 30-40 L/every 45 days)) (The Alameda 2008), 3) all the year- palms with symptoms and highly infected palms: (1 M/L 30-40 L/every 45 days) (The Alameda 2008), and 4) all the year- highly infected palms: removal of fronds, fungicide and/or growth regulators (The Alameda 2008). Small-scale area management involves the control of RPW in small farms and in quarantine. Several management methods were used successfully for this purpose. Area wide management program provide a large-scale area management at long term. Hoddle *et al*. (2013) reported that area wide management program proved efficient and fast

In order to achieve the RPW management objectives, various detection, prevention and treatment methods are tested and / or applied against RPW. Among them there are multi purpose methods that can be used for the three purposes. Actually, using one method will not give the desired result (Hussain *et al*. 2013a; Vidyasagar and Aldosary 2011), accordingly, all tested methods should be combined in an integrated pest management strategy (IPM) for best results (Abbas 2010; Aldryhim and Al-Bukiri 2003; Conti *et al*. 2013; Hussain *et al*. 2013a; Massa *et al*. 2013; Soroker *et al*. 2013; Vidyasagar and Aldosary 2011). RPW IPM strategy was developed firstly on coconut then it was modified on date palm (Abraham *et al*. 1998; Faleiro 2006a, 2006b; Faleiro *et al*. 1998). Risk prediction and assessment are essential topics to determine the critical control point before recommending and deciding RPW management strategy, furthermore they are essential to evaluate the efficacy of the adopted management program. Different procedures were used successfully in RPW risk prediction and assessment such as sequential sampling based risk assessment (Faleiro *et al*. 2010), ecological niche modeling (ENM) (Fiaboe *et al*. 2012), palm thermal constant (Mozib and El-Shafie 2013; Salama *et al*. 2002) and the infestation risk (IR) symptoms classes (Pontikakos and Kontodimas 2013). Location aware system (LAS) is a geographical information system (GIS) (Barranco *et al*. 2006; Massoud *et al*. 2011; Pontikakos and Kontodimas 2013; Soroker *et al*. 2013), it applies different techniques to detect, take decision, protect and treat RPW infestation in large areas (Pontikakos and Kontodimas 2013). Early detection of RPW is an essential topic for the success of management procedures, where the palm heart is still healthy and the trunk is still stable. Furthermore, it will prevent the emergence and migration of adult weevils (Carmelo *et al*. 2011; Faleiro 2006a; Faleiro *et al*. 1998; Hallett *et al*. 1999; Mankin 2011; Mozib and El-Shafie 2013; Peri *et al*. 2013; Pontikakos and Kontodimas 2013; Soroker *et al*. 2013). So they should be effective, sensitive, specific and rapid (Soroker *et al*. 2013). Although there were different early detection methods they are not practical and not adapted to large scale area, (Soroker *et al*. 2013). These methods include visual, acoustic (sound), olfactory (smell) detection either by naked sense organs or by automatic detectors, image processing system, electromagnetic signatures and/or semiochemical-based methods. The early detection requires the availability of data and information such as palm species, palm location, RPW population characteristics, risk assessment, among others (Barranco et al. 2006; Faleiro *et al*. 2010; Massoud *et al*. 2011; Pontikakos and Kontodimas 2013; Soroker *et al*. 2013). These data and information should be available in up to dated version (Pontikakos and Kontodimas 2013). Image processing based techniques are detection methods that detect either the presence of RPW individuals or the symptoms of infestation. Preventive methods can decrease the reproductive potential of RPW, but do not prevent the infestation of palm trees in the infected areas. However, it can prevent the spread of RPW to non-infected areas (Ferry and Gomez 2012). RPW preventive methods include training and education, legislative control, cultural control, biological and chemical treatment. Preventive treatments every 60 days effectively reduce costs and increase the survival of the palm trees (Ferry and Gomez 2012). RPW monitoring includes the use of different attractants such as semiochemicals in combination with traps to catch a portion of the pest (mass trapping). In the RPW IPM program,

RPW is mass trapped by kairomone traps, pheromone traps, Pheromone/Kairomone traps and / or Pheromone / mineral oil traps. The combination of kairomone and pheromone in mass trapping results in synergistic effect on RPW catch. These traps can be a method of early detection hence preventive and / or a curative method in case of trapping large number of RPW (Gunawardena and Gunatilak 1993).

This book 'RED PALM WEEVIL' serves as a review of literature book that considers the state and progress of the fundamental and applied research on RPW. I wrote it to fulfil the increase need of an up to dated multi topics review source on RPW, where a review article is not enough for this purpose. 'RED PALM WEEVIL' is intended to be used as a consultation comprehensive review on RPW. It is not intended neither to be a methodology source nor a management guide. This book addresses lecturers, undergraduate and graduate students, researchers and anyone who is interested to know about RPW.

I wrote this book in simple English to be easily readable by people whose first language is not English as this pest attracts the attention of people from over the world. I arrange the data and information of this book in different sections. I separated the text, figures and tables in separate section each to facilitate the reading. As well, each section can be consulted independently. The text is included in two sections: section I deal with the general characteristics of RPW, and section II deal with its management. Each section is subdivided into different chapters (19 chapters). Regarding the figures, I preferred not to add figures for the management tools or devices as they are updated continually and are available on several web sites and companies' catalogues.

I wrote 'RED PALM WEEVIL' using different sources such as books, general and specific review articles, research articles, conference abstracts, different web sites and personal communication as well my personal conclusions.

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I GENERAL CHARACTERISTICS

1 TAXONOMIC STATUS

Rhynchophorus ferrugineus (Olivier 1790), Red Palm Weevil (RPW) is classified under genus *Rhynchophorus* (Herbst 1795), family Curculionidae, subfamily Rhynchophorinae (Dryophthorinae), order Coleoptera (Lepesme 1947; Rugman-Jones *et al*. 2013; Wattanapongsiri 1966). *Rhyncho* and *Ferruginueus*s are Greek words, where *Rhyncho* refers to their snout beak while *Ferruginueus*s refers to RPW rusty red color (Wattanapongsiri 1966). See Tables (1-4) for more details on *Rhynchophorus* spp.

Rhynchophrus spp. are so close and so variable in the same time (Lepesme (1947). One or more of *Rhynchophorus* spp. may be synonymous to RPW (Murphy and Briscoe 1999; Wattanpongsiri 1966). Hence, their taxonomic status needs to be revised (Murphy and Briscoe 1999). Genetic studies using different loci and/or cross-mating studies may due to the detection of *Rhynchophorus* cryptic species (Rugman-Jones *et al*. 2013). *R. lobatus* is synonymous either with *R. ferrugineus* or *R. vulneratus* (Wattanapongsiri 1966).*R. vulneratus* was considered as a color morph of RPW (Hallett *et al*. 2004) as the two were found to be alike in morphological characters, RAPD banding patterns, mitochondrial DNA (*Cytochrome oxidase subunit* 1 (CO1) gene analysis), host plant preference, pheromone production and response, the lack of reproductive isolating mechanism and the existence of color inter-morphs (Hallett 1996; Hallett *et al*. 1993, 2004; Perez *et al*. 1996). In contrast, Abulyazid *et al*. (2002) found no similarity in RAPD banding patterns between the two species. Later, Rugman-Jones *et al*. (2013) confirmed that RPW and *R. vulneratus* were two separate species, where they detected genetic variation between the two species using CO1 gene analysis.

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See Lepisme (1947) and Wattanapongsiri (1966) for more information on the *Rhynchophorus* species identification key.

2 STRUCTURAL CHARACTERISTICS

2.1 SEX

The RPW female is similar to the male in size, color and the black spots on the pronotum, while it differs from it as follows:

1) the absence of rostral setae (Lepesme 1947; Wattanapogsiri 1966),
2) its rostrum is snout longer, slender, and cylindrical (Lepesme 1947; Wattanapogsiri 1966),
3) the absence of setae on the front femur (Lepesme 1947; Wattanapogsiri 1966),
4) its setae on the front tibia is much shorter (Lepesme 1947; Wattanapogsiri 1966), and
5) its last abdominal segment is less curved without hair (MOEW 2014).

2.2 MORPHOLOGICAL CHARACTERISTICS

2.2.1 ADULT STAGE

Shape and size. RPW adult is elongate oval, its size ranged from 19 to 42 mm in length and 8 to 16 mm in width for male while it ranged from 26 to 40 mm in length and 10 to 16 mm in width for female (Wattanapogsiri 1966).

RPW body color is ferrugineus (rusty red) to black, legs color is lighter, elytra color is dark red to black, rostral color vary from ferrugineus to black (Lepesme 1947; Wattanapogsiri 1966).

Antenna. RPW antenna is geniculate clavate type. It has a long scape, followed by a pedicel and a flagellum (5 segments known as funicle, the sixth called club); the club color is ferrugineous (Lepesme 1947; Mahmoud *et al*. 2012; Wattanapongsiri 1966).

Mouth parts. RPW chewing mouth parts are simple with ferrugineus to black rostrum, smooth to minutely punctured, long (four fifth of pronotum length), curved, straight and broad at base, male has a tuft of hairs on the dorsal surface of the rostrum (Lepesme 1947; Vidyasagar and Aldosary 2011; Wattanapongsiri 1966), rostral setae is absent (Lepesme 1947).

The upper and lower incisor cusps of the mandibles are rounded and longer in males than in females. The inner margins of the cusps meet at an angle of 45° and ≥ 45° in female and male respectively (Salama and Abdel Aziz 2001). The distal segment of the maxillary palp bears 22 and 13 sensillae basiconica in females and males respectively, the sensillae on the buccal cavity projected toward the center of the oral cavity, where they are groups of different shape and length finger-like sensillae basiconica in females, while they are multiporous peg sensillae in males (Salama and Abdel Aziz 2001).

Thorax. RPW thorax divided into three parts: prothorax (same length as the head), mesothorax (quadrate, one six of the thorax length) and metathorax (quadrate, clear pleura uncoated with elytra) (Wattanapongsiri 1966).

RPW front wings (elytra) are soft velvety, do not cover the last abdominal segment (Viado and Bigornia 1949), masked with dark stripes (narrow furrows) (Lepesme 1947; Vidyasagar and Aldosary 2011; Wattanapongsiri 1966), its length is one and one third its width (Wattanapongsiri 1966), the hind wings are long and narrow (Viado and Bigornia 1949).

RPW legs consist of three regions: 1) the femur: long and thin (100 μm), sharp spines present in one side of the femur plus short and wide thorns, 2) the tibia, and 3) the tarsus: (5 tarsomeres), the distal tarsomer consists of two tarsal claws (Lepesme 1947).

Abdomin. RPW abdomenal color is ferrugineus to black (Wattanapongsiri 1966), its shape starts flattened then narrowed gradually towards the end (Viado and Bigornia 1949), the length of the first abdominal sterenite is shorter than the second one while equal to the length of both the third and the fourth sterenites combined (Wattanapongsiri 1966).

2.2.2 LARVAL STAGE

RPW larva type is cruciform, apodus (Paddy 2009), its head is hard sclerotized, nearly round, a uniform capsule color (usually dark brown) (Dambilio and Jacas 2011; Wattanapongsiri 1966). It is legless, creamy white (Hussain et al. 2013a; Paddy 2009), smooth body except for the presence of scarce long and thin sensilla (Dambilio and Jacas 2011), It grows up to 5 cm length (Hussain et al. 2013a), its width ranged from 0.51 (1^{st} insar) to 8.24 (13^{th} instar) mm, based on larval weight (Dambilio and Jacas 2011).

2.2.3 PUPAL STAGE

RPW pupal type is exarate. Its size ranged from 72 to 40mm in length and 13 to 16mm in width (Wattanapongsiri 1966). Pupation occurs in about 4cm long oval, cylindrical cocoon (Hussain *et al*. 2013a).

The pronotum bears two pairs of tubercie-borne setae, tiny spines distributed, the Metanotum bears one pair of tubercleborne setae, the length of the Scutellum is four fifths or more of metanotum, with one pair of tubercle-borne setae, The elytra do not cover the first abdominal spiracles (Wattanapongsiri 1966).

2.2.4 EGG

RPW eggs vary in shape and embryonic development (Al-Dawsary *et al*. 2010), they are creamy yellow color (Dembilio *et al*. 2011a; Haussain *et al*. 2013a), elongated oval, cylindrical, smoothly rounded, their ends are rounded, their anterior ends are slightly narrow (Haussain *et al*. 2013a; Wattanapongsiri 1966).

Their length estimated by 1.09 mm (Dembilio *et al*. 2011a), 2.96 mm (Wattanapongsiri 1966), and 2.8 mm (Haussain *et al*. 2013a) while their width estimated by 0.43 mm (Dembilio *et al.* 2011a), 0.98 mm (Wattanapongsiri 1966), and 1mm (Haussain *et al*.
2013a).

The egg micropylar apparatus consists of two micropylar opening close to the center of the egg posterior wide pole. Each micropylar is a single small oriflce, its surrounding chorion is porous and densely set with tiny projection allowing the spermatozoa to penetrate the egg (Al-Dawsary *et al*. 2010).

Respiratory aeropyles are distributed on the borders of reticulations on the egg capsule chorionic surface (Al-Dawsary *et al*. 2010).

2.2.5 SPERM

The individual sperm of RPW consists of three major divisions: 1) the head, comprising one-eighth the length of the sperm, 2) a relatively straight tail filament, and 3) a sinuate tail filament. The two tail filaments are tightly joined at the head and at the terminal tip of the tail. In the anterior area of the sperm head, there are dark particles which may be an indication of the presence of an acrosome and centriole (Bartlett and Rananavare 1983).

2.2.6 SENSILLAE

Antennal sensillae. RPW uses the sense organs on the antenna as mechanoreceptors, sex, aggregation pheromone, olfactory, heat, humidity receptors (Mahmoud *et al*. 2012). Wattanapongsiri (1966) identified 8 to 15 setae on the antennal inner side of the spongy area. Mahmoud *et al*. (2012) identified four types (11 subtypes) of sensillae on RPW antenna, theses types are similar in both males and females: Sensillae basiconica (SBI & SBII) (Mahmoud *et al*. 2012; Salama and Abdel Aziz 2001), Sensillae cuticular pores: (Mahmoud *et al*. 2012; Salama and Abdel Aziz 2001), Sensillae chaetica (hair-like structure): two subtypes (SCHI & SCHII) (Mahmoud *et al*. 2012), Sensillae coeloconica (styloconica): three subtypes (SCI (finger-like appearance), SCII & SCIII) (Mahmoud *et al*. 2012; Salama and Abdel Aziz 2001) and Sensillae trichodea: four subtypes (STI, STII) (Mahmoud *et al*. 2012; Salama and Abdel Aziz 2001), (STIII, STIV) (Mahmoud *et al*. 2012). Mahmoud *et al*. (2012) identified two, six and seven subtypes of sensilla on the pedicel, flagellum and club respectively.

Thorax and abdominal sensillae. Al-Dawsary (2013) identified four types (12 subtypes) of sensillae on RPW thorax and adomena: Sensillae basiconica, Sensillae bifid tricoid hair, Sensillae coeloconica (styloconica) (six subtypes) and Sensillae trichodea (four subtypes). The sensillae on the terminal ninth abdominal segment of the ovipositor distributed on the dorsal, medial and ventral plates and leaflets (paired), the sensillae on the anal leaflets are of four types (Salama and Abdel Aziz 2001).

Infrared receptor (IR) (IR sensilla). RPW uses the IR sensilla for seeking oviposition localities (Ragaei and Sabry 2013).

Ragaei and Sabry (2013) reported that infrared receptors are distributed on the larvae and pupae cuticle as well on the adult's wings; they also observed infrared absorbance area (spores) on the cuticle and wings.

2.3 MORPHOLOGICAL COMPARAISON AMONG *RHYNCHOPHORUS* SPP.

Lepesme (1947) mentioned that *Rhynchophrus* species were so close and so variable in the same time, and he found that it was not useful to describe them in details; accordingly, he described their general morphological characteristics briefly. However, Wattanapongsiri (1966) demonstrated a comprehensive description of the different morphological characteristics and measurements of ten *Rhynchophrus* spp.

Rugman-Jones *et al*. (2013) estimated three morphometric parameters of the pronotal shape (ratio of minimum to maximum pronotal width (MinW/MaxW); ratio of minimum pronotal width to pronotal length (MinW/PL); and, ratio of pronotal length to transect length (PL / TL)) of three *Rhynchophorus* spp.: *R. bilineatus*, *R. ferrugineus* and *R. vulneratus*. They found variation among the three species but they did not detect any variation within each species. The female of *R. ferrugineus* was bigger (MinW/PL) than the female of *R. vulneratus*. *R. ferrugineus* had a more square shaped pronotum (ilarger MinW / MaxW) than *R. vulneratus*.

2.4 SALIVARY GLANDS AND DISTRIBUTION OF DOPAMINE AND SEROTONIN

RPW salivary glands are tubular type; they are responsible for regulation of feeding via serotonin and dopamine (Hidayah *et al*. 2013). Serotonin and dopamine may act as hormones, as they were seen on few areas within the glands; they did not not act as neurotransmitter as they did not innervate the glands (Hidayah *et al*. 2013).

2.5 TYPES AND ROLE OF RPW HEMOCYTES IN DEFENSE REACTIONS

Five major hemolymph cell types from last RPW larval instar were identified: 1) plasmatocytes (different sizes with smooth surface and long philopodia) (50 %), 2) granular hemocytes (granulocytes) (30 %), 3) oenocytes (4 %), 4) prohemocytes (round small or large cells with rough surface) (8 %), and 5) spherulocytes (3 %) (Manachini *et al*. 2011). Both the plasmatocytes and granulocytes were involved in nodules, capsule formation and phagocytosis of non-self organisms, such as *Saccharomyces cerevisiae*, where granulocytes bind to target cells, degranulate, and then plasmatocytes form a multilayer sheath (Manachini *et al*. 2011). The granulocytes degranulation allowed the plasmatocytes recruitment; also, it was responsible for different agglutinating inflammatory factors (Manachini *et al*. 2011). As a response to the infection by an entomopathogeneic organism such as *Bacillus thuringienses* (BT), the number of total hemocytes (mainly plasmatocytes) declined sharply (to 12 %) then rest at a low level, other types of hemocytes did not change (Manachini *et al*. 2011).

2.6 RPW PROTEINS

Al Jabr and Abo-El-Saad (2008) isolated a putative serine protease from RPW larval gut, where its major band had a molecular weight of approximately 24kDa as mammalian trypsin. Alarcon *et al*. (2002) isolated and identified RPW digestive proteases from larval gut. The isolated proteases subdivided according to its molecular mass into three groups: 1) high molecular mass protease (HMP) (80-100 kDa), 2) medium molecular mass protease (MMP) (30-66 kDa), and 3) low molecular mass protease (LMP) (16-24 kDa) (Alarcon *et al*. 2002). The presence of both trypsin-like and chymo-trypsin-like activities was observed, where the amount of trypsin activity was 2 to 6 times higher than chymo-trypsin activity (Alarcon *et al*. 2002). Proteolytic activity of Gut homogenate (30 day old RPW larvae) (hydrolysis of the azocasein) showed an alkaline optimum pH range (9.0–10.0), where the highest activity achieved at pH 9.5/0.1 mg casein/24 hrs/ room temperature (Alarcon *et al*. 2002). The protease was relatively inactive (15 % activity) below pH5, whereas 70 % activity was recorded at pH12 (Alarcon *et al*. 2002). The protease activity increase

from the 5^{th} day to the 35^{th} day of larva l age, the activity decrease at the 20^{th} day where it was equal to the 5^{th} day, this might due to the degradation or the decrease of the synthesis of the digestive protease due to the decrease of food intake near the next molt , this decrease in enzyme activity might be related to anatomical and physiological modification. A linear relationship between the agglutination activity and the insect age was observed (Abdally *et al*. 2010). The hem-agglutination activities of midgut (MG) fractions of RPW against mammalian erythrocytes (RBC) from man (ABO), rabbit, horse and sheep were studied. The highest titers were seen with rabbit RBC ($p < 0.05$) followed by human group B, human group O, horse, human group A, human group AB and sheep, respectively.The protein content of the feeding material affects the protease activity, where the highest activity was observed on semi-artificial diet (15 % protein) followed by *Phoenix canariensis* (4 % protein), the least activity was observed on sugarcane where it was two times less than the semi and four times less than palm (Alarcon *et al*. 2002).

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See Wattanapongsiri (1966) for more information on the morphological characteristics of Rhynchophous species.
See Table (7) for information on the effects of feeding materials on different RPW stages weight; Table (8) for information on the effects of feeding materials on different RPW morphological parameters.

3 LIFE CYCLE

The entire life cycle of RPW ranged from 45 to 298 days. The duration of all the life parameters varied significantly depending on the feeding material and environmental factors (Dambilio and Jacas 2012; Esteban-Duran *et al*. 1998; Faleiro 2006a; Kaakeh 2005; Murphy and Briscoe 1999).
Several overlapping generations were observed inside a single infested palm (Faleiro 2006a), where up to three generations could occur in one year inside the palm (Abe and Sone 2009; Dembilio *et al.* 2009b; Hoddle *et al*. 2013).
The number of eggs laid by female ranged from 33 to 500 eggs. Their incubation period ranged from one to ten days depending on the feeding material. See Tables (5-9) for more details.

3.1 Adult Stage

RPW adult is a strong flier that can fly from one to seven km during the early period of the day and the last hours before sunset, for two days (Abbas *et al*. 2006; Hoddle 2013; Kalshoven 1981; Nirula 1956; Sedra 2012; UAEIR 2006). The flight activity differed according to the season (Hoddle 2013). Male life span is shorter than female life span (Salama *et al*. 2009) with one to more than 100 days difference.
Pre-ovipositional period ranges from one to eleven days (Alsuhaibani *et al*., 2001; El-Ezaby 1997; Frohlich and Rodewald, 1970; Kaakeh 2005; Lepesme 1947).
Males produce a pheromone that attract females to aggregate for mating, mating behaviors included rostral rubbing, antennal tapping (placating gestures) and guarding (to forbid other males from approaching and mating with the female) (Al-Ayedh 2011; Al-Ayedh and Rasool 2009; Wattanapongsiri 1966). Multiple mating (Al-Ayedh 2011; Kaakeh 2005) is observed in RPW.
The copulatory period for the female insemination was short (an average of 2.9–4.8 min) (Kaakeh 2005).
RPW female has the ability to store male sperms, so one mating is enough for producing viable eggs (Abraham *et al*. 2001; Kaakeh 2005). Accordingly, RPW has a high multiplication potential rate (one female/five million new RPW individuals/four generations/14 months) (Nirula 1956).
Females start oviposition in short time after copulation (Kaakeh 2005). The oviposition continues through out the year (Dembilio *et al*. 2011a; Faleiro 2006a).
Females laid eggs in narrow holes (Alsuhaibani *et al*. 2001) made with their rostrum (Nirula 1956), most frequently in soft portions of fresh host tissues or in wounded and/or on damaged trees (Alsuhaibani *et al*. 2001; Bartlett and Rananavare 1983; Gunawardena and Bandarage 1995; Kalshoven 1981; Mankin 2011; Sadakathulla 1991; Salama *et al*. 2009), in crown or at leaf scars in young coconuts (Kalshoven 1981), in cracks, cervices, at leaf axel, at offshoot emergence sites (Salama *et al*. 2009) and within the new emerged roots (Abraham *et al*. 1998) or trunk (Bartlett and Rananavare 1983) on young date palms, with more preference of palms of 5 to 20 years old (Faleiro 2006a).
Although Kaakeh (2005) reported that weevils failed to infest wounds with stiff tissues, healthy trunks or roots, Murphy and Briscoe (1999) observed that undamaged palms can also be attacked.

RPW laid eggs together but not contacted, then produce cemented material to cover the holes to protect the eggs (Dembilio *et al*. 2011a; Murphy and Briscoe 1999; Salama *et al*. 2009).

The number of eggs laid ranges from 33 to 500 eggs per female. This variation depends on different host cultivars (Bartlett and Rananavare 1983), different diets in laboratory and female age (Kaakeh 2005). The mean number of eggs laid by the female decreased significantly: 1) with increasing weevil age, and 2) when females confined with males (Kaakeh 2005).

The maximum number of eggs in KSA was recorded during August, October and March, where it was 72, 60 and 78 respectively (Abbas and Al-Nasser 2012).

Incubation period ranges from 2 to 18 days depending on the feeding material and the temperature. The percentage of hatchability (viability of eggs) ranges from 30 % to 94 %. Eggs laid during the summer, hatches faster compared to the eggs laid during winter (Abraham *et al*. 2001).

Under laboratory conditions, the viability variation may depend on food type (Kaakeh 2005), temperature (El-Ezaby 1997; Kaakeh 2005) and rearing methodology (Kaakeh 2005).

In laboratory experiments, when females were reared with and without males, they laid viable eggs throughout their life span except for the last 17 and 39 days before death, respectively. However, these observations are not likely to have bearing on the damaging potential of the pest as most of the eggs were laid during the first four weeks itself (Kaakeh 2005). Adults either stays inside the palm to re-mate or leave it when fresh tissues are depleted and the palm meristem get damaged.

3.2 Larval Stage (Grub)

New hatched RPW larvae exposed for some hours to the outer environment before entering to the inside where it spends all its life (Salama *et al*. 2009). Larvae feed voraciously, thereby destroying the palm (Bartlett and Rananavare 1983). The larvae can only bore in soft

tissues found on the crown, upper part of the trunk, at the base of the petioles (Bartlett and Rananavare 1983; Gunawardena and Gunatilake 1993; NAPPO 2008), into the trunk of young palms, the decaying tissue of dying palms (Murphy and Briscoe 1999), injured tissues, central stalk below the outer skin of the tree and fresh bark (Mogahed 2010). In these parts, larvae congregate and feed further (Gunawardena and Gunatilake 1993). Larvae chew the plant tissue and move towards the interior of the palm, leaving behind chewed-up frass (plant fibers), which have a typical fermented odor. Frequently, the frass protrudes through the holes on the infested stem/petiole (it can be hidden in tunnels of 15 to 20cm deep) (MOEW 2014).

Three to 17 larval instars are observed, the duration of larval stage ranges from 24 to 182 days. The variation in instar number may due to the natural or artificial diet and rearing conditions, a researcher's counting error and/or competition among the larvae for food that make them molt in an inconsistent manner (Faleiro, personal Communication 2011). The number of instars calculated based on the measurement of head capsule (Dembilio and Jacas 2012).

3.3 Prepupal and Pupal Periods

The completely developed grubs move towards the internal part of the trunk, petioles and/or to the periphery of the stem (Salama *et al*. 2009), then form an oval cocoon from chewed fibers and pupate inside it (Dembilio and Jacas 2012; Faleiro 2006a; Murphy and Briscoe 1999; Salama *et al*. 2009). The prepupal developmental period ranges from two to twenty days while the pupal period ranged from ten days to several months.

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See Table (5a, b, c, d) for information on the biological parameters of RPW: life cycle duration; Table (6a, b, c, d) for information on the biological parameters of RPW: numbers of instars, egg production, hatching % and average egg production); Table (9) for information on the effects of feeding materials on different RPW biological parameters.

4 NATURAL HOST RANGE

RPW is reported on several palm species (Arecaceae) (Dembilio *et al*. 2009a; EPPO 2008a; 2008b; Faleiro 2006b; Hussain *et al*. 2013; Malumphy and Moran 2009; Yin *et al*. 2013). It is reported from 50 % of date palm growing countries and 15 % of the coconut growing countries all over the world (Faleiro 2006b).

RPW is reported mainly on: *Cocos nucifera* (the Coconut palm tree) in Indian sub-continent and China (Dembilio and Jacas 2012), where it was considered as its serious pest early in 1918 in the Indian Museum Notes (Nirula 1956), *Phoenix dactylifera* (the date palm) in Arabian Peninsula and Pakistan, *Ph. canariensis* (the Canary Islands date palm) in the Mediterranean basin (Dembilio and Jacas 2012). *Ph. Canariensis* and *W. filifera* are more preferred by RPW than *Ph. Silvestris* (Ju *et al*. 2010). See Table (4) for more details. RPW prefers palms of less than 20 year old (Abraham *et al*. 1998; Faleiro 2006b; Nirula 1956). RPW is reported on various cultivars of date and coconut palms (Faleiro 2006b; Krishnakumar and Maheswari 2004). Mazafati variety is the most preferred host for RPW in Iran (Farazmand 2002). Khalas, Reziz, Shish and Hatmi varieties were preferred by RPW while Khasab, Shahal and Gaar are non-preferred (Faleiro and El-Shafie 2013). Al-Ayedh (2008) reported that Sukkary variety was the best compared to Khalas, Sukkary, Khasab, and Sillaj varieties, where it showed the highest growth, length, width and weight for larval, pupal and adult stages, also, the highest number of laid eggs. This may due to its highest sugar content (El-Lakwah *et al*. 2011). In addition, adult lifespan was longer on Khasab (Al-Ayedh 2008).

Faleiro (2006b) observed that RPW can not complete its life cycle on the wild palm *Nannorrhops ritchiana*. The European Union (EU 2007) considered *Chamaerops humilis* and *Washingtonia filifera* as RPW hosts. However, different experiments showed that neither *Ch. humilis* (antixenosis resistance mechanism: the fronds has fibrous base) (Liacer *et al*. 2012) nor *W. filifera* (antibiosis resistance mechanism: gummy secretion cause RPW mortality) (Dembilio *et al*. 2009a) nor *Ph. theophrasti* (antibiosis resistance mechanism) (Dembilio *et al*. 2009a) could be infected naturally. However, wound or wind damaged *Ph. theophrasti* and *Ch. humilis* got infected (Dembilio and Jacas 2012).

RPW was also observed on *Agave Americana* (Agavaceae) (Hussain *et al*. 2013). Malumphy and Moran (2009) reported that Saccharum *officinarum* was a host for RPW. However, Abbas and ElSebay (2013) observed that RPW females could not infest sugarcane as they could not neither lay their eggs on the external layer nor feed, on the other hand, they could complete their life cycle when fed on sugarcane pieces in laboratory.

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See Table (4a, b, c, d, e) for information on the geographical distribution and host range of RPW.

5 ALTERNATIVE FEEDING MATERIALS

A mass number of insects is required in order to study them (El-Sebay *et al*. 2003; Rananavare *et al*. 1975). A development of alternative feeding materials is essential for mass rearing of RPW, as its rearing on its natural host plants is difficult due to the palm size that requires space and high cost (Rahalkar *et al*. 1978). Developing cell culture would be an alternative approach to study RPW. The feeding on natural materials other than natural host or artificial diets affects different morphological, biological and behavioral parameters (Al-Ayedh 2011; Alsuhaibani *et al*. 2001; Ju *et al*. 2010; Kaakeh 2005; Mogahed 2010; Rahalkar *et al*. 1972).

5.1 NATURAL FEEDING MATERIAL

Different natural plants were tested as alternative host for RPW in laboratory rearing and experiments (Tables 5-10). Mogahed (2010) reported that the fresh barks and injured sites of Fig (*Ficu scarica*), Guava (*Psidium guava* (L.)), and Mango (*Mangifera indica* (L.)) were vulnerable food source for RPW, while Lime (*Citrus medica*), Mandarin (*Citrus aurantium var. deliciosa* & *var. amara* (L.)) and Olive (*Olea sativa*) were less attractive for it (Mogahed 2010). On the other hand, Sour Orange (*Citrus aurantium*) was not attractive at all to RPW.

The use of pieces of date palm was more advantageous than sugarcane (Al-Ayedh 2008) or fruit tress (Mogahed 2010). The pieces of date palm are easily available, contain needed minerals and cheaper compared to sugarcane (Al-Ayedh 2008). Mogahed (2010) mentioned that they resulted in the highest consumption rate, larval weight average (more than three folds), pupation and adult emergence compared to different fruit trees. On the other hand, Al-Ayedh (2008) observed that sugarcane pieces were suitable as feeding materials for larvae due to their suitability for pupation. Al-Ayedh (2008) mentioned that Khasab date palm cultivar was the best for RPW laboratory rearing. Date fruits were better than banana or sugarcane as bait for pheromone traps (Al-Saoud 2011a). Abdalah and Al-Khatri (2005) and Al-Saoud (2009) observed that the quantity of date fruit per trap had an impact on the effectiveness of the traps. Mizzi *et al*. (2009) concluded that banana plant was not preferred host by RPW, where they observed a high mortality rate of RPW and low percentage of adult emergence (37 %) when reared on banana.

5.2 ARTIFICIAL DIET

The artificial diets should include the main nutrient components necessary for the growth and development of insects such as nitrogen source (protein or free amino acids), lipids, carbohydrates, vitamins, minerals, stabilizers, preservatives and fillers or bulking agents (Cohen 2003). Also, it is important to add host plant materials to the artificial diet as they consist of nutritional elements in suitable proportions for the correct growth and development of insects (Cohen 2003). According to different authors RPW larvae were reared successfully on different artificial (semi-synthetic) diets. The semi-synthetic diet included (Tables 5-9): -sugarcane agasse, coconut cake, yeast, sucrose, essential minerals, vitamins, food preservatives, agar, water (Rahalkar *et al*. 1972), -potatoes or sweet potatoes, carrot, glucose, casein, agar, cereals, vitamin B, vitamin D and water (El-Sebay *et al*. 2003), -Oat, potato, pineapple, palm fiber sheath, bacto-agar, multi-vitamins and water (Kaakeh 2005) or -Maize flour, wheat flour, shredded date palm frond tissue, protein, amino acids, carbohydrates, starch, lipids and distilled water (Al-Ayedh 2011).

Rearing RPW on the artificial diet: Agar 20 g, Distilled water 880 ml, Brewers yeast 50g, Wheat germ 50 g, Corn meal 50 g, M-nipagine 1.8 g, Benzonic acid 1.8 g, Ascorbic acid 4.5 g, Chloramphenicol 0.5 g, Coconut fiber 8 g, Vitamin and amino acid additive1 50 ml, 15 % Crude protein (dry weight) (Barranco *et al*. 1997) resulted in a complete pattern of digestive proteases, hence, it was recommended as arearing diet for research purposes (Alarcon *et al*. 2002).

The highest protease activity was observed when RPW larvae were fed on this diet and on *Phoenix canariensis*, followed by *Trachycarpus fortunei* where the least activity was observed on *Saccharum officinarum* (Alarcon *et al*. 2002).

5.3 CELL CULTURE

Aljabr *et al*. (2014) developed a mid gut epithelial cell culture (RPW-1). They found that Grace's medium was the most effective for culturing RPW-1 followed by Schneider's medium, TNM-FH medium and Media-199. The optimal temperature and relative humidity for culturing RPW-1 were at 27 °C, 27 °C, 24 °C, and 21 °C and pH 6.3, 6.4, 5.3, and 7 for Grace's medium, Schneider's medium, TNM-FH medium, and Media-199 respectively (Aljabr *et al*. 2014). Aljabr *et al*. (2014) studied the effect of different pesticide on RPW-1; they found that emamectin benzoate pesticide caused 92 % mortality and 74% growth inhibition, while Dieldrin caused 19 % mortality and 18 % growth inhibition.

5.4 EFFECTS OF FEEDING MATERIALS ON DIFFERENT RPW MORPHOLOGICAL PARAMETERS

RPW larvae became brownish, shrinking and weak when fed on different fruit trees comparing to the white yellowish, normal shape and active larvae fed on date palm trunk and/or top (Mogahed 2010). There was no significant difference in RPW pupal average weight when RPW fed on palm tissues compared to those fed on artificial diet (Al-Ayedh 2011). However, differences in RPW pupal weight average were recorded when RPW fed on different artificial diet (Kaakeh 2005). RPW adult male and female gained weight when fed on artificial diet compared to palm tissue (Al-Ayedh 2011). See Tables (7, 8).

5.5 EFFECTS OF FEEDING MATERIALS ON DIFFERENT RPW BIOLOGICAL PARAMETERS

Feeding material had effects on development, survival and reproduction (Ju *et al*. 2010). It affected as well the development of the digestive enzymatic system (Alarcon *et al*. 2002). Differences in all biological parameters were found when RPW fed on different artificial diet (Kaakeh 2005). No significant difference was observed in Egg production or hatchability when RPW fed on palm tissues compared to those fed on artificial diet (Al-Ayedh 2011). Shorter larval developmental time and one more larval instar were observed when RPW fed on artificial diet compared to palm tissues (Al-Ayedh 2011). Significant differences in the developmental time were observed in the first, fifth, seventh, eighth, tenth and eleventh larval instars when RPW fed on palm tissues and artificial diet, with small change of one to two days (Al-Ayedh 2011). The host plant may affect the longevity of male life span where it was reduced significantly on different verities (Al-Ayedh and Rasool 2010). Date palm varaities with high calcium content inhibit the RPW growth, while varieties with high sugar content enhanced growth and egg laying and reduce mortality (Farazmand 2002). The variety Khalas was more preferable by RPW than the varieties Shahal and Murheim in KSA, where the former enhanced egg laying (Al-Bakshi *et al*. 2008). See Tables (9).

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See Table (5a, b, c, d)for information on the biological parameters of RPW: life cycle duration; Table (6a, b, c, d) for information on the biological parameters of RPW: numbers of instars, egg production, hatching % and average egg production; Table (7) for information on the effects of feeding materials on different RPW stages weight; Table (8) for information on the effects of feeding materials on different RPW morphological parameters; Table (9) for information on the effects of feeding materials on different RPW biological parameters; Table (10) for information on the RPW infestation levels of different palm varieties.

6 TEMPERATURE

Temperature is an important factor affecting the biology, ecology and population dynamic of PPW due to its poikilothermic nature (Dembilio and Jacas 2012). However RPW biological behavior may not severely affected in infested palms (Dembilio *et al*. 2011a; Mozib and EL-Shafie 2013) due to the difference of temperature between the inner of infested palm and the temperature of its outer environment (Mozib and El-Shafie 2013; Salama *et al*. 2009).

6.1 PALM TEMPERATURE

The temperature of the infested palm increases gradually with the increase of infestation, where it can be detected in the third week post infestation (Mozib and El-Shafie 2013).

The temperature of infested palm is higher than the temperature of the healthy one (Abe *et al*. 2010; Mozib and El-Shafie 2013; Salama *et al*. 2009; Suma and Longo 2009), with a difference of 0.8-2.63 °C (Mozib and El-Shafie 2013; Salama *et al*. 2009). Those temperatures are above the minimum and below the maximum of the outer temperature (Mozib and El-Shafie 2013).

The difference between the infested palm temperature and the environmental temperature ranges from 1.20-12.07 (Mozib and El-Shafie 2013), 4.1 (during winter, December-February) to 6.6 ° C (during summer, August) (Salama *et al*. 2009).

The increase of the infested palm temperature may due to the intensive fermentation of plant tissue as a result of RPW feeding (Abe *et al*. 2010; Suma and Longo 2009) or may due to other unknown factors as the palm temperature increased even in the presence of few RPW individuals (Dembilio and Jacas 2011). See Table (11)

6.2 EFFECTS OF TEMPERATURE ON DIFFERENT RPW BIOLOGICAL BEHAVIOUR

Oviposition and egg hatching. The negative effect of temperature on the RPW ovipositin behavior affects its infection severity (Dembilio and Jacas 2011; Dembilio *et al*. 2011a). The RPW oviposition and fecundity rates increased with the temperature increase in the range of 10 to 25 °C (Dembilio *et al*. 2011a). The maximum values were observed at 25 °C, while no oviposition occurred at temperatures less than 20°C (Dembilio *et al*. 2011a).

When RPW larvae were reared at 25 °C, and then moved when reached 14 days old to 15 °C or 10 °C, an 84 to 98 % reduction of oviposition and fecundity occurred respectively.

Difference in egg hatching was not significant neither when RPW reared at 25, 23 or 20 °C nor when it reared on 25 °C then moved to 23, 20 0r 15 °C at 14 days old (Dembilio *et al*. 2011a). A reduction of 83.5 % in egg hatching was observed when RPW reared at 25 °C then moved to 10 °C at 14 days old (Dembilio *et al*. 2011a).

The LTTs for RPW oviposition and egg hatching under the Mediterranean conditions were close to mean annual temperature in most Northern shore of the Mediterranean basin and below the mean winter monthly temperature of most countries of the northern shore of the Mediterranean basin (Dembilio *et al*. 2011a). Accordingly, no new palm infestation would be expected during most of the winter in this area (Dembilio *et al*. 2011a). This may explains the reduced infestation rate in winter in the Middle East (Abraham *et al*. 1998).

The RPW oviposition and hatching periods were estimated in some Mediterranean basin countries based on the LTTs for both RPW oviposition and egg hatching and mean monthly temperature (MMT) (Dembilio *et al*. 2011a). The two periods would be longer in the northern shore of the basin than the southern, oviposition would stop during the coldest winter where the oviposition period begins from early April to mid-October-early November, while the egg hatching period (EHP) begins from mid-March to mid/late October and continue during the year (Dembilio *et al*. 2011a). Oviposition would stop during the coldest winter months, while egg hatching would continue during the whole year in the southwestern part of the Basin (Dembilio *et al*. 2011a). See Tables (12, 13, 14).

Developmental time. A negative relationship between developmental times of different RPW stages and temperature values more than LLT was observed where, developmental times took less times in summer than winter (Dembilio and Jacas 2011; Salama *et al*. 2002). See Table (13).

Larval mortality rates. The maximum RPW survival rates were noticed in *P. canariensis* (Spain) infested from April through September, while the maximum mortality rates were noticed in those infected either in January or December (100 %) (Dembilio and Jacas 2012). Neonate larvae were more sensitive to the lower temperatures than older immature stages (Dembilio and Jacas 2012). The mean monthly temperature less than 10.3 °C was lethal to recently hatched larvae (Martin and Cabello 2006), while 4.5 °C was lethal to the older larvae and immature stages (Dembilio and Jacas 2012).

Pupal stage. Pupal stage could develop under wide range of temperatures; accordingly pupation occurred through out the year in Egypt (Salama *et al*. 2002). The favorable temperatures ranged from 15 °C (February, 24.2 days pupation, 1.19 cycles of weevil emergence) to 29.3 °C (August, 3.14 days pupation, 2.3 cycles of weevil emergence) (Salama *et al*. 2002).

The thermal threshold ranged from -2.3 to 44-45 °C (Salama *et al*. 2002). The thermal constant K differs greatly within summer season this may due to feeding materials and/or RPW characteristics (Dembilio *et al*. 2011a). Dembilio *et al*. (2011a) mentioned that the differences among LTT due to the differences in the climatic conditions of the geographic area supports the genetic variation results of El-Mergawy (2011, 2012, 2013) and El-Mergawy *et al*. (2010). See Tables (12, 13, 14, 15).

Number of annual generations. A linear relation between the mean annual temperature (MAT), mean maximum temperature (MMT), and mean minimum temperature (MmT) and the number of RPW generations per year was observed.

One generation per year can be expected in areas with mean annual temperature <15 °C (Northern shore), while more than two generations per year would be expected in the area with mean annual temperature <19 °C (Southern shore) in the Mediterranean area (Dembilio and Jacas 2011). Accordingly, Dembilio and Jacas (2011) concluded that *P. canariensis* in Iberian Peninsula takes two years minimum to be killed by RPW as two to three generations were necessary while in Northern Spain more than this period.

Larval head capsule. There is a Relationship between mean head capsule width per instar and cumulated heat units (DD) above lower temperature threshold (Dembilio and Jacas 2011).

RPW activity. The weather conditions of a given area have a direct impact on the number of weevils caught by the pheromone trap. High weevil captures are obtained when moderate weather conditions prevail while weevil captures drop during the summer and winter seasons and during the heavy monsoon (Faleiro *et al*. 1998). A maximum number of attracted weevils occurred during May in KSA (Ajlan and Abdulsalam 2000). The highest mean cumulative catch per trap was recorded between 18:00 and 00:00 (Faleiro and Satarkar 2003b). In an experiment conducted in Villainy, Kerala, India, the mean number of weevils caught were significantly higher in lowlands followed by that in garden lands and uplands, this may due to the succulence of the tissues of the trunk in those palms in wetlands and garden lands, facilitating easy egg laying by the adults and also easy penetration of larvae into the trunk (Krishnakumar and Maheswari 2004).

6.3 EXPERIMENTAL TEMPERATURE

The palm stem temperature varied from 24 to 28 °C (Alsuhaibani *et al*. 2001),accordingly, The temperature and relative humidity during the experimental period were justified at 25 °C & 30-50 % R.H (KSA) (Al-Ayedh 2011); 27°C & 85 % R.H (Egypt) (El-Sebay *et al*. 2003), 28-29 ± 2 °C & 55-90 % R.H (India) (Rahalkar *et al*. 1978); 21 °C & 70.1 % R.H (Egypt) (Salama and Abdel-Razek 2002; Salama *et al*. 2009), or 27-29 °C (A.-Fetouh 2011).

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See Table (11) for information on the temperature of healthy and RPW infested palm and the surrounded environment; Table (12) for information on the effects of temperature (10-25 °c) on fecundity rate, ovopostion rate and percentage of hatchability of RPW at laboratory; Table (13) for information on the thermal cumulated degree days (DD) for the development of different RPW stages, the lower temperature threshold (LTTs) for different RPW stages, fecundity, ovipositin and egg hatching; Table (14) for information on the oviposition and egg hatching periods based on mean monthly temperatures in the Mediterranean basin; Table (15) for information on the pupal duration and rate of weevil emergence in Egypt.

7 DIURNAL AND SEASONAL ACTIVITY OF RPW

RPW showed diurnal activity during sunrise and sunset in Sultanate of Oman (Al-Khatri and Abdallah 2003) and other countries (Faleiro 2005; Faleiro 2006a). Also it was observed active between midnight-0600 h in India and between 1800-0800 h in Sri Lanka (Faleiro and Satarkar 2003a; Gunawardena and Bandarage 1995), this may due to weather differences, as in Goa (India) the monsoon is restricted between June and September while Sri Lanka receives rain almost throughout the year (Faleiro 2006a).

Weather as a whole has a significant impact on RPW activity (Faleiro 2005). There is a positive relationship between temperature and RPW activity, while there is a negative relationship between the rainfall and activity RPW (Faleiro 2005).

Seasonal activity of RPW varies significantly among months and within the same month. It is more active in the warmer months than the cooler ones. See Tables (16).

The highest activity of RPW occurred during worm seasons from March until November (Abbas 2013).

RPW population increased gradually from January (Abbas 2013; Abbas *et al*. 2000), or November (Ajlan and Abdulsalam 2000) until reaching the maximum in March (Abbas 2013; Abbas *et al*. 2000), April (Abbas *et al*., 2000), or May (Abbas *et al*. 2000; Ajlan and Abdulsalam 2000; Faleiro 2006b) when it becomes warmer, then decreases gradually until reaching the minimum in August (Ajlan and Abdulsalam 2000; Faleiro 2006b).

The high activity of RPW during the wormer months may due to the emergence of broods whose development is slowed by the cooler months (El Garhy 1996). However, in summer (June–September), when the temperature reaches an average of 42.8 °C (39–48 °C) during day, the population of RPW decreases, as it may hide in the infested date palms or inhabit the soil seeking shade (Abbas *et al*. 2000).

RPW was less active during the monsoon between June and July, while it was highly active after the monsoon between October and November (Faleiro 2006b).

The RPW infestation under the Mediterranean climate decreased after winter (Abraham *et al*. 1998), due to the decrease of developmental rate of RPW with decreasing autumn-winter temperature (Dembilio and Jacas 2011); however, the microclimatic temperature did not limit the RPW development inside the tree, (Dembilio *et al*. 2011a) as it is 4 to 6 °C higher than outside (Salama *et al*. 2009).

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See Table (16) for information on the maximum and minimum RPW adult activity in different countries.

8 GEOGRAPHIC DISTRIBUTION

The commercial exchanges of the offshoots among and within different countries facilitated the rapid spread and the extension of the RPW range of expansion (Abraham *et al*. 1998; Murphy and Briscoe 1999). RPW local extension occurred either with the same mechanism or as series of secondary invasion (EL-Mergawy 2011, 2012, 2013).

Origin and distribution. The geographic origin of RPW is claimed literally to be Southeast Asia and Melanesia (Abraham *et al*. 1975; Ferry and Gomez 2002; Loqma and Alqaeit 2002; Murphy and Briscoe 1999; Wattanpongsiri 1966). Genetic analysis using CO1 confirmed this claim as it revealed that RPW was native to the northern and western parts of continental Southeast Asia, Sri Lanka and Pakistan, the Philippines, Vietnam, India and Cambodia (Rugman-Jones *et al*. 2013).

RPW has been recorded in different localities belonging to Africa, Asia, Central America and Caribbean, Europe and the Oceania. It has been introduced to the Middle East in the mid 1980's (Bokhari and Abuzuhari 1992; Gomez and Ferry 1999). Subsequently, it has been moved to North Africa, Europe, Australia and South America and Caribbean Islands.

Spatial distribution pattern. RPW follow the negative binomial clumped aggregated contagious pattern of distribution (Faleiro *et al*. 2002, 2010)

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See Table (3a, b, c) for information on the geographical distribution and host range of *Rhynchophorus* spp; Table (4a, b, c, d, e) for information on the geographical distribution and host range of RPW.

9 CYTOLOGY AND GENETIC

9.1 RPW KARYOTYPE

Bartlett and Rananavare (1983) reported that RPW karyotype consisted of 10 pairs of meta-centric autosome chromosomes and one pair of sex chromosome showing male XY heterogamety, the Y chromosome had either a dot or a metacentric appearance.

9.2 RPW GENETIC RESOURCES

Wang *et al*. (2013) and Yin *et al*. (2013) established two datasets of RPW complementary DNA (cDNA) sequencing; they generated five million reads assembled in 26765 contigs, and 80 to 91 million reads assembled in 22 532 genes respectively.

Wang *et al*. (2013) reported that more than 80% of coding sequences had high identity to known proteins. The pupal gene showed the highest expression level while the larval gene showed the lowest level. In addition, they identified more than 60000 single nucleotide polymorphisms (SNP) and 1200 simple sequence repeat markers. Yin *et al*. (2013) found that 30.45% of the transcripts of five embryonic developmental stages expressed differentially, 10.10% showed stage-specificity and 62.88% exhibited constitutive expression in all the stages. They provided a resource for gene annotation and RPW functional genomics, as well they analyzed the dynamics of expression of several conserved signaling pathways and key developmental genes (apoptosis, axis formation, Hox complex, neurogenesis and segmentation).

9.3 GENETIC VARIATION AMONG RPW MORPHOLOGICAL FORMS

Genetic variation was not detected among the different prothorax forms of RPW neither using mitochondrial markers (*Cytochrome b* (*Cyt*b) (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011b, 2011c) and *Cytochrome oxidase c subunit* 1 (CO1)) (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011b, 2011c; Rugman-Jones *et al*. 2013), nor using nuclear region (ITS2) (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*., 2011b; 2011c; Rugman-Jones *et al*. 2013) 28S-D2 (Rugman-Jones *et al*. 2013). On the other hand, random amplified polymorphic DNA (RAPD-PCR) patterns showed that: 1) black spotted forms were more related than the non spotted forms (Salama and Sakr 2002) and 2) Brown forms with & without black spots were more related than black non spotted forms (Al Ayied *et al*. 2006).

9.4 GENETIC VARIATION OF RPW POPULATIONS

Different genetic variation studies done on different geographic and local RPW (Abulyazid *et al*. 2002, Al-Ayied *et al*. 2006; El-Mergawy 2012, 2013; El-Mergawy *et al*. 2010, 2011b, 2011c; Gadelhak and Enan 2005; Hallett *et al*. 2004; Rugman-Jones *et al*. 2013; Salama and Saker 2002). In those studies six types of molecular markers were used: 1) CO1 (El-Mergawy 2012, 2013; El-Mergawy *et al*. 2010, 2011a, 2011b, 2011c; Hallett *et al*. 2004; Rugman-Jones *et al*. 2013), 2) *Cyt*b (El-Mergawy 2012, 2013; El-Mergawy *et al*. 2011b), 3) ITS2-rDNA (El-Mergawy 2012, 2013; El-Mergawy *et al*. 2011b), 4) 28S-D2 (Rugman-Jones *et al*. 2013) sequences, 5) RAPD-PCR (Abulyazid *et al*. 2002, Al-Ayied *et al*. 2006; El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2010; Gadelhak and Enan 2005; Hallett *et al*. 2004; Salama and Saker 2002), and 6) microsatellites (Capdevielle-Dulac *et al*. 2012).

9.4.1 MITOCHONDRIAL GENETIC VARIATION

Mitochondrial genetic variation and invasion history of RPW were investigated using *Cyt*b (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011b) and CO1 genes (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011c; Rugman-Jones *et al*. 2013).

***Cyt*b.** RPW genetic variation using *Cyt*b gene was investigated among RPW from invaded countries belonging to different continents such as 1) Africa: Egypt; 2) Asia: KSA, and Turkey; 3) Europe: Cyprus, France, Greece, Italy and Spain (mainland and Canary Islands) (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011b).

A genetic variation of 4.2 % nucleotide substitutions was detected dividing the tested individuals into several haplotypes. A total of 3 haplotypes (El-Mergawy-HB1, El-Mergawy-HB2 & El-Mergawy-HB3) were detected (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011b). However, no intra-specific variation was detected (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011b). The haplotype El-Mergawy-HB1 was the most geographic distributed one, where it was found in 8 different countries belonging to three different continents: 1) Africa – Egypt, 2) Asia - KSA, Turkey and 3) Europe - Spain (mainland and Canary Islands), Italy, Greece, Cyprus and France (El-Mergawy 2011, 2012, 2013). The wide geographic distribution pattern of this haplotype may indicate a very high invasive potential when introduced by human, accordingly this haplotype was called the invasive haplotype (El-Mergawy 2011, 2012, 2013). The invasive haplotype was fixed in RPW from different localities in each country. This can be explained by a unique introduction event, a single successful one or multiple introductions of the same haplotype. Rapid expansion of the invasive haplotype in different localities could have resulted from a series of secondary invasion events through transportation of infested young or adult date palm trees and offshoots from contaminated to uninfected areas (El-Mergawy 2011, 2012, 2013). The other haplotypes were detected in Asian countries such as: Iran (El-Mergawy-HB2), Oman, Pakistan and UAE (El-Mergawy-HB3) (El-Mergawy 2011, 2012, 2013).

CO1. RPW genetic variation using CO1 gene was investigated among RPW from the claimed native countries such as Cambodia, India, Malaysia, Philippines, Sri Lanka, Thailand and Vietnam (Rugman-Jones *et al*. 2013). As well RPW from invaded countries such as 1) Africa: Egypt (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011c); 2) Asia: KSA (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011c; Rugman-Jones *et al*. 2013), Israel (Rugman-Jones *et al*. 2013), Syria, and Turkey (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011c); 3) Europe: Cyprus (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011c; Rugman-Jones *et al*. 2013), France, Greece, Italy, Spain (mainland and Canary Islands) (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011c) and Portugal (Rugman-Jones *et al*. 2013); 4) South America: Curacao and Aruba (Rugman-Jones *et al*. 2013).

A genetic variation of 4.2 % nucleotide substitutions was detected dividing the tested individuals into several haplotypes. A total of 43 haplotypes (H1-H43) were detected (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011c; Rugman-Jones *et al*. 2013).

CO1 intra-specific variation was detected in Cambodia (2 haplotypes), Cyprus (2 haplotypes), India (5 haplotypes), Israel (2 haplotypes), KSA (2 haplotypes), Malaysia (2 haplotypes), Oman (3 haplotypes), Pakistan (2 haplotypes), Philippines (9 haplotypes), Sri Lanka (3 haplotypes), Thailand (6 haplotypes), UAE (4 haplotypes), Vietnam (8 haplotypes) (see Table 17 for references). The presence of more than one haplotype may due to the introduction of RPW from different source populations; or only one source, either through different introduction events or from a single one containing more than one haplotype (El-Mergawy 2011, 2012, 2013). The 43 CO1 haplotypes subdivided into two sisters' phylogenetic groups: group 1 included RPW from both native and invaded area while group 2 included RPW from native countries.

Genetic distances (GDs) among all the haplotypes ranged from 0.015 (H22 & H38) to 0.046 (H12 & H43). GDs between the El-Mergawy H8 haplotype and the other haplotypes ranged from 0.035 (El-Mergawy H8 & H12) to 0.019 (El-Mergawy H8 & H38).

Among the 43 detected CO1 haplotypes, 34 haplotypes were recovered from the native area while 10 haplotypes were recovered from the invaded countries. The El-Mergawy-H8 haplotype was the most geographic distributed one, where it was found in different countries and Islands belonging to four different continents:

1) Africa: Egypt (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011c).

2) Asia: KSA (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011c), Israel, Malaysia, Thailand (Rugman-Jones *et al*. 2013) and Turkey (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011c).

3) Europe: Cyprus, France, Greece, Italy, Spain (mainland and Canary Islands) (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011c) and Portugal (Rugman-Jones *et al*. 2013).

4) South America: Curacao (Rugman-Jones *et al*. 2013).

The wide geographic distribution pattern of this haplotype may indicate a very high invasive potential when introduced by human, accordingly this haplotype was called the invasive haplotype (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011b, 2011c). Rapid expansion of the invasive haplotype in different localities could have resulted from a series of secondary invasion events through transportation of infested young or adult date palm trees and offshoots from contaminated to uninfected areas (El-Mergawy 2011, 2012, 2013). The invasive haplotype (as well other haplotypes) was fixed in RPW from different localities in each country (El-Mergawy 2011, 2012, 2013). This can be explained by a unique introduction event, a single successful one or multiple introductions of the same haplotype (El-Mergawy 2011, 2012, 2013). The El-Mergawy-H8 haplotype was recovered from countries belonging to both the invaded (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011c) and the claimed native area (Rugman-Jones *et al*. 2013). It was detected in Thailand and Malaysia; accordingly, Rugman-Jones *et al*. (2013) suggested that the geographical origin sources of RPW populations in the Mediterranean Basin were Thailand and Malaysia. The El-Mergawy H8 haplotype was grouped with the haplotypes from Cambodia, Philippines and Vietnam (Rugman-Jones *et al*. 2013), so more intensive sampling in these areas might uncover the El-Mergawy-H8 haplotype (Rugman-Jones *et al*. 2013). Rugman-Jones *et al*. (2013) hypothesized that RPW invaded the Middle East through Pakistan but Pakistan was not its source origin.

The other haplotypes that were detected in the invasive area such as El-Mergawy H1-H6 (Oman, Pakistan, Syria and UAE), El-Mergawy H7 (Japan) (El-Mergawy 2011, 2012, 2013), H17 (Israel and KSA), H20 (Aruba), and H33 (Cyprus) (Rugman-Jones *et al*. 2013) were not detected in the native range. However, El-Mergawy H1-H7 grouped with haplotypes H9-H16 that were detected from claimed native area; India and Sri Lanka (Rugman-Jones *et al*. 2013). Rugman-Jones *et al*. (2013) mentioned that it was likely that the origin of El-Mergawy H7 from an area in the north western part of the native range, not sampled in this study; perhaps in India, Bangladesh, or Myanmar. The H20 haplotype was detected in Aruba a neighboring Island to Curacao. Rugman-Jones *et al*. (2013) hypothesized the presence of H20 in Aruba and not in the other invaded countries as follow: RPW was introduced once to the Caribbean, where H20 was a rare haplotype so it was not detected in the other invaded countries, H20 was a post invasion mutation of El-Mergawy H8 haplotype as the two differed in only one nucleotide or RPW was introduced more than one time to the Caribbean from similar native area. The H33 haplotype was detected in Cyprus, there were 11 nucleotides difference than the El-Mergawy H8 haplotype, and it was grouped with the El-Mergawy H8 haplotype and the haplotypes that were detected from Cambodia and the Philippines (Rugman-Jones *et al*. 2013).

Demographic parameters such as Tajima's D neutral test, FST (genetic differentiation) and Nm (gene flow) values calculated among the different geographical populations showed that the tested invaded populations of RPW diverged genetically under the influence of genetic drift likely through multiple founder events (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011b, 2011c).

9.4.2 NUCLEAR GENETIC VARIATION

Genetic variation among RPW from different countries using the sequences of two separate conserved regions of nuclear ribosomal RNA ITS2-rDNA (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011b; Rugman-Jones *et al*. 2013) and 28S-D2 (Rugman-Jones *et al*. 2013) showed no polymorphism (El-Mergawy 2012, 2013; El-Mergawy *et al*. 2011b; Rugman-Jones *et al*. 2013).

This absence of genetic variation can be explained by a strong concerted evolution (Elder and Turner 1995; Graur and Li 2000).

9.4.3 MICROSATELLITE MARKERS

Capdevielle-Dulac *et al*. (2012) isolated 15 polymorphic microsatellite markers from RPW. These markers will probably show more variability when studied on populations of the area of origin of the species. They will also help identifying the sources of the invading populations and discovering the invasion pathways.

9.4.4 RAPD-PCR PATTERN

Genetic variation among thirteen geographic populations of RPW collected from Egypt, KSA, Turkey, Spain (mainland and Canary Islands), Italy, Greece, Cyprus, France, Iran, Japan, Oman, Pakistan, and UAE, was investigated using RAPD-PCR (El-Mergawy 2011, 2012, 2013).

Cluster analyses of RPW populations showed that:

1) RPW subdivided according to their geographic positions into two major groups (El-Mergawy 2011, 2012, 2013):

(I) The Multi-continent: included RPW from countries belonging to three continents; Africa, Asia and Europe.

(II) The Asian group: subdivided into two Asian groups:

II-1) Included Japanese RPW and,

II-2) Included other Asian RPW.

Genetic similarities among the three groups ranged from: 30-40 % between 1) group I and II-1 and 2) group I and II-2, while it ranged from 20-30 % between group II-1 and II-2 (El-Mergawy *et al*. 2010; 2012, 2013). RAPD analysis revealed that genetic similarities among RPW populations were higher than those among individuals. Genetic similarities ranged from 0 to 70 % among geographical populations (Abulyazid *et al*. 2002; El-Mergawy 2011, 2012, 2013) and 30 to 94 % among local populations (Abulyazid *et al*. 2002; Gadelhak and Enan 2005; El-Mergawy 2011, 2012, 2013). On the other hand, genetic similarities among RPW individuals from either same country or different countries ranged from 0 to 80 % (El-Mergawy 2011, 2012, 2013).

Comparison among RPW from different countries:

Geographic populations (RPW from different countries). Genetic similarities ranged from 0 to 70 % among RPW geographical populations (Abulyazid *et al*. 2002; El-Mergawy 2011, 2012, 2013), where it was 0 % between Egypt and KSA (Abulyazid *et al*. 2002), 20 % (between KSA and Japan, and 70 % between KSA and UAE (El-Mergawy 2011, 2012, 2013).

Individuals (RPW individuals from different countries). Genetic similarities ranged from 0 % between individuals from Egypt (AlMinufiyah2) and individuals from Japan (Japan1) to 80 % between individuals from Egypt: (BurSaid1) and individuals from Turkey (Turkey2) (El-Mergawy 2011, 2012, 2013).

Comparison among RPW from the same country:

Local populations (RPW individuals from different localities in the same country).

Genetic similarities ranged from 30 to 94 % among local populations (Abulyazid *et al*. 2002; Gadelhak and Enan 2005; El-Mergawy 2011, 2012, 2013).

Egypt. Genetic similarities ranged from 20 % (between AlBuhayrah & Banisuayf and AlBuhayrah & Aswan) to 80 % (between AlQalyubiyah & AlWadialjadid and Dumyat & Kafrasshshykh) (El-Mergawy 2011, 2012, 2013).

Individuals (RPW individuals from the same country). Genetic similarities ranged from 0 % (Cyprus) to 80 % (Japan) (El-Mergawy 2011, 2012, 2013).

Egyptian individuals. Genetic similarities ranged from 20% (between AlJizah2 and AlIsmailiyah2) to 80 % (between AlFayyum2 and Dumyat1) (El-Mergawy 2011, 2012, 2013).

According to the observed genetic distances: at the geographic population level: there was positive correlation between the genetic distances and the geographic distances among the tested geographic populations of RPW from 13 different countries (El-Mergawy 2011, 2012, 2013). In contrast, no correlation was found among RPW from Egypt, KSA and Indonesia, where RPW from KSA was found to be related to RPW from Indonesia but not RPW from Egypt (Abulyazid *et al*. 2002). At the local geographic pattern: 1) there was no correlation between the genetic distances among individuals from different localities in UAE and the geographic ones (Gadelhak and Enan 2005) and 2) not all the Egyptian individuals have direct relationships with local geographic pattern as some individuals from distant localities were clustered together: 1) Ash Sharqiyah, Aswan and Bani Suwayf, 2) Al Qalyubiyah, Al Wadi al Jadid and Ash Sharqiyah and Al Fayyum and Iskandariyah (El-Mergawy 2011, 2012, 2013).

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Conclusions:

1) Genetic studies using mitochondrial and RAPD comparison revealed that RPW followed three different routes of invasion (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011c): one towards the East of the area of origin that gave rise to the Japanese haplotype and two routes towards the West (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011c).

2) The western area divided in the West between Middle East, where 6 haplotypes were found and the Mediterranean basin where the invasive haplotype El-Mergawy H8 (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011c), in addition to H17 (Israel and KSA) H20 (Aruba) and H33 (Cyprus) (Rugman-Jones *et al*. 2013).

3) These three invasion roads are corresponded to three different genetic lineages of RPW populations that had independent evolutionary histories (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011c).

4) RPW populations that invaded the Middle East and the Mediterranean area likely came from two different geographical origins. One is the source of the Egyptian and related Mediterranean populations and the other is the source of the Arabic Peninsula (KSA, UAE & Oman) and Asian populations (Pakistan & Iran) (El-Mergawy 2011, 2012, 2013; El-Mergawy *et al*. 2011c).

9.5 GENETIC COMPARISON AMONG RPW AND OTHER *RHYNCHOPHORUS* SPP.

9.5.1 TAXONOMIC STATUS OF *RHYNCHOPHORUS* SPP.

Rugman-Jones *et al*. (2013) suggested that genetic studies using different loci and/or cross-mating studies might due to the detection of *Rhynchophorus* cryptic species.

***R. ferrugineus* and *R. vulneratus*.** Hallett *et al*. (2004) believed that *R. vulneratus* was a color morph of RPW as the two were found to be alike in morphological characters, RAPD banding patterns, CO1 DNA, host plant preference, pheromone production and response, the lack of reproductive isolating mechanism and the existence of color inter-morphs (Hallett 1996; Hallett *et al*. 1993, 2004; Perez *et al*. 1996). Rugman-Jones *et al*. (2013) reported that the morphological differences were not evident to distinguish between *R. ferrugineus* and *R. vulneratus*. Accordingly, they proposed that the palm weevils from Singapore, Sumatra, Java and Bali be referred as *R. vulneratus* while those from the north and east of the Thai-Malay Peninsula is referred as *R. ferrugineus*.

***R. ferrugineus*.** It was reported that the CO1 divergence level of species boundaries (3%) (Hebert *et al*. (2003, 2004) (as cited in Rugman-jones *et al*. (2013))). Rugman-jones *et al*. (2013) mentioned that the 43 CO1 haplotypes of RPW were divided into 3 sub-groups differed from each other by 2.5 to 3.2%. Hence, they assumed that one or more of these subgroups might represent a separate cryptic species.

***R. vulneratus*.** Rugman-Jones *et al*. (2013) detected 3 substitutions differences within *R. vulneratus* ITS2 sequences.

9.5.2 GENETIC VARIATION AMONG RHYNCHOPHORUS SPP.

CO1. Rugman-jones *et al*. (2013) reported that the CO1 divergence between *R. bilineatus, R. ferrugineus* and *R. vulneratus* was >13 %.

ITS2. Rugman-jones *et al*. (2013) reported that *R. ferrugineus* differed from *R. vulneratus* with 11-14 substitutions and a single base deletion, while *R. bilineatus* differed from both *R. ferrugineus* and *R. vulneratus* with several substitutions and 24 nucleotide deletions. Accordingly, they confirmed that *R. ferrugineus* and *R. vulneratus* are different species from *R. bilineatus*.

28S-D2. Rugman-jones *et al*. (2013) did not detect any differences between *R. bilineatus* and *R. vulneratus* 28S-D2 sequences. While they found two substitutions differences between *R. ferrugineus* and *R. bilineatus.*

RAPD. Abulyazid and his colleagues (2002) detected genetic variation among four different *Rhynchophorus* spp. using RAPD analyses: RPW from Egypt, and the Indonesian archipelago, *R. vulneratus* from Venezuela, *R. palmarum* from Costa Rica and *R. cruentatus* from Florida-USA.

Geographic distribution of *Rhynchophorus* spp. Haplotypes

Rugman-Jones *et al*. (2013) cited that:

1) the distribution of *R. bilineatus* haplotypes (RB1-RB8) restricted to Papua New Guinean,

2) *R. ferrugineus* haplotyps (43 haplotypes) had a northern and western distribution, and

3) *R. vulneratus* haplotypes (Rv1-Rv62) had a more southeastern distribution (Singapore, the Indonesian islands of Sumatra, Java, and Bali, and the invasive population in California).

4) *R. ferrugineus* and *R. vulneratus* haplotypes overlapped in southern Thailand and northern Malaysia on the Thai-Malay Peninsula. The geographic area of overlapping was close to Although Wattanapongsiri (1966) suggested that *R. ferrugineus* and *R. vulneratus* present in the Philippines, Rugman-Jones *et al*. (2013) did not detect the presence of *R. vulneratus* in the Philippines.

EL-Mergawy (2011, 2012, 2013) reported that the mitochondrial (CO1) genetic similarities among *R. bilineatus*, *R. cruentatus*, R. *ferrugineus*, *R. palmarum* and *R. vulneratus* ranged from 91.9 to 94.2%.

R. palmarum appeared as the most distantly related species to the currently analyzed ones (El-Mergawy 2011, 2012, 2013).

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See Table (17) for information on the geographical distribution of RPW CO1 haplotypes.

10 SYMPTOMS OF INFESTATION

The concealed nature of RPW makes its detection difficult before it completely damages the palm (Abraham *et al*. 1998, 2001; Faleiro 2006b; Morrison 2013; Mukhtar *et al*. 2011; Soroker *et al*. 2013). However, several researchers proved that the presence and damage of RPW infestation could be detected at early stages (Ferry and Gomez 2012; Gutierrez *et al*. 2010; Soroker *et al*. 2013). The developed symptoms are categorized according to different parameters (Ferry and Gomez 2012). Theses symptoms include 1) physical symptoms (Abdallah and Al-Khatri 2000b; Al-Bakry 2012; El-Ezaby 1997; Faleiro 2006b; Ferry and Gomez 2012; Gunawardena and Gunatilake 1993; Hallett *et al*. 1999; Soroker *et al*. 2013; Vidyasagar and Aldosary 2011), 2) physiological changes (Mozib and El-Shafie 2013; Soroker *et al*. 2013), and 3) protein expression change (Aldawood *et al*. 2013).

10.1 POSITION OF INFESTATION

Ferry and Gomez (2002) reported that RPW larvae could be found in any place within the palm. Different authors observed that RPW infestation occurred mostly at the lower position of palm stem (0-100 cm) (Aldryhim and Khalil 2003; Azam *et al*. 2001; Lukmah and Alquat 2002; Osman *et al*. 2001). where the infestation at 0 to 50 cm of stem was higher than the infestation at 50 to 100 cm and 100 to 150 cm levels (El-Lakwah *et al*. 2011). El-Sebaey (2004a) observed the presence of alive RPW on the emerged roots in the soil. Abbas *et al*. (2000) concluded that RPW adults might inhabit soil, seeking shade and shelter, their conclusion based on different observations such as: 20 to 100 % of trapped RPW were parasitized with unidentified non pathogenic nematodes, buried traps captured 2 to 3 fold RPW, compared to aerial ones (1 to 1.5 m height), and young date palm (3 to 10 years old) showed severe infestation by RPW at or below soil surface. Ferry and Gomez (2002) mentioned that as the larvae inhabited the site where the roots emerged, they were found in the soil.

10.2 PALM CATEGORIES

RPW infestation symptoms developed depending on the palm type. Palm types are categorized into three categories: (I) palms of less than 2 to 3 m high, (II) palms of more than 2-3 m high with offshoots and/or wounds at the lower part of the trunk and (III) palms of more than 2 to 3 m without offshoots or wounds at the lower part of the trunk (Ferry and Gomez 2012). Regarding category (III) RPW larva feed and hide themselves in the outer base of the trunk without penetrating or entering inside it so they do not make cavity. RPW larva cannot be seen in early stage but its feeding effects on the palms can be detected early on the foliage by naked eyes (Ferry and Gomez 2012).

10.3 SYMPTOMS CATEGORIES

The developed symptoms are categorized as follow:

10.3.1 LEVELS OF INFESTATION

Symptoms are categorized according to the level of infestation into three categories:
(I) early, (II) medium, and l
Symptoms also are categorized according to the infestation risk IR into ten categories each levy is given a number from one to ten (Pontiacs and Kontodimas 2013), where level 1 refers to the healthy palm while level 2 refers to infested palm, the levels 3 to 10 refer to different symptoms and level 11 refers to a severe infestation where the palm must be removed (Pontikakos and Kontodimas 2013).

10.3.2 POSSIBILITY TO SAVE THE PALM

Symptoms are categorized according to the possibility to save the palm into five level: none (palm cannot be recovered), very low, low, medium and high (Soroker *et al*. 2013).

10.4 DEVELOPED SYMPTOMS

Damage due to RPW may result in one or more of the following symptoms:

10.4.1 PHYSICAL SYMPTOMS

Offshoots

Small offshoots. Yellowing, drying and death of the fronds, making them to be removed easily showing a dry and moldy heart (Abdallah and Al-Khatri 2000b; Al-Bakry 2012; El-Ezaby 1997; Faleiro 2006b; Ferry and Gomez 2012; Gunawardena and Gunatilake 1993; Hallett *et al*. 1999; Soroker *et al*. 2013; Vidyasagar and Aldosary 2011).

Old offshoots. Partial yellowing of the fronds (Abdallah and Al-Khatri 2000b; Al-Bakry 2012; El-Ezaby 1997; Faleiro 2006b; Ferry and Gomez 2012; Gunawardena and Gunatilake 1993; Hallett *et al*. 1999; Soroker *et al*. 2013; Vidyasagar and Aldosary 2011).

Palm trees. Gnawing sound due to feeding by grubs, partial or total yellowing fronds, dangling of the fronds, a large cavity at the top of the palm, cuts at the terminal and/ or central parts of the fronds (scissor-like cut straight lines), holes (tunnel openings) appeared on scraped trunk, tunnels at all directions in the trunk and the bases of leaf petioles, brown chewed plant tissues, RPW frass in and around opening of tunnels, oozing out of thick brown fluid from the tunnels with a typical fermented odor, fallen empty pupal cases and dead adults around a heavily infested palm, breaking of the trunk or toppling of the crown in case of severe or prolonged infestation, in cases of infected hearts, central fronds became partially or totally yellowish, heart infection due to the death of palm within 6 months or less (Abdallah and Al-Khatri 2000b; Al-Bakry 2012; El-Ezaby 1997; Faleiro 2006b; Ferry and Gomez 2012; Gunawardena and Gunatilake 1993; Hallett *et al*. 1999; Soroker *et al*. 2013; Vidyasagar and Aldosary 2011).

Symptoms differences between palm species: 1) *Phoenix dactylifera*: RPW develops in the lower part of the trunk, oozing wounds, the palm may appear healthy until late stage of infestation; 2) *Phoenix canariensis* Hort. ex Chabaud: Crown infestation is common, no oozing, crown symmetry changes. The wilt of internal crown fronds is more common in *Cocos nucifera* L. and *Ph. canariensis* than *Ph. dactylifera* (Soroker *et al*. 2013).

10.4.2 PHYSIOLOGICAL CHANGES

The feeding of RPW inside the palm destroys the palm vascular system causing water stress like conditions; this stress is reflected by higher canopy temperature and lower stomatal conductance as compared with non infected palms (see Soroker *et al*. 2013 for references). The larval feeding effects on temperature occurred in the first two to three weeks of infestation (Mozib and El-Shafie 2013).

10.4.3 PROTEIN EXPRESSION

RPW infestation due to protein expression differences between RPW healthy and infested palms, this was proven using 2D-DIGE (two-dimensional differential gel electrophoresis) (Aldawood *et al*. 2013).

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11 RPW ASSOCIATED ORGANISMS

Different organisms such as: bacteria, fungi, nematodes, virus and yeast were isolated from the surrounded environment of RPW and studies as potential tools for biological control.
RPW associated with microorganisms, these microorganisms should be Included in studies on the interactions between RPW, its plant hosts, and its enemies.

11.1 NATURAL ENEMIES

Different organisms such as: bacteria, fungi, nematodes, virus and yeast were isolated from the surrounded environment of RPW and studies as potential tools for biological control.

1.2 SYMBIOTIC BACTERIA

The symbiotic bacteria prevent the growth of any other microorganisms in the host providing suitable conditions for nematode reproduction (Dowds and Peters 2002; Gaugler and Kaya 1990; Smigielski *et al*. 1994). It releases through the EPNs anus in the host haemocoel where it proliferates, provides food to the new colon that causes the host death (Dowds and Peters 2002; Gaugler and Kaya 1990; Smigielski *et al*. 1994).

11.3 FRASS AND GUT MICROORGANISMS

Khiyami and Alyamani (2008) revealed that aerobic and facultative anaerobic bacteria are more distributed in the gut of RPW such as (*Bacillus* sp., *Salmonella* sp., *Enterococcus* sp. and *Xanthomonas* sp.).

Butera *et al*. (2012) characterized the bacteria associated with RPW larval gut and frass (in palm tunnels). Gut bacteria were cellulolytic and hemicellulolytic, frass bacteria were associated with RPA larva and were dominated by 2, 3-butanediol fermented Enterobacteriaceae. The isolated bacteria could not degrade cellulose.

11.4 ANTIMICROBIAL ACTIVITY OF RPW

Mazza *et al*. (2011b) have studied the antimicrobial activity of the cuticular surface of all RPW stages. Their study revealed that that there are polar compounds ranged from 1000 to 1500 Dalton are responsible for RPW microbial inhibition. Those components could inhibit the growth Gram-positive bacteria (*Bacillus subtilis* and *B. thuringiensis*) and the EPF *Beauveria bassiana* while they could not inhibit neither the growth of the Gram-negative bacterium *Escherichia coli* nor the growth of the fungus *Metarhizium anisopliae*. On the other hand, RPW hemolymph showed no inhibition effect.

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See section II-17 for additional information on RPW natural enemies

See Table (18a, b, c) for information on the isolated natural enemies of RPW.

Phoretic relationship: an 'interaction that enhances dispersal, benefiting the disperser without impacting the phoretic host (Holte *et al*. 2001).

12 WHY RPW IS A SUCCESSFUL INVADER?

The successful invasion of RPW as cited in El-Mergawy and Ajlan (2011) may due to:

1) Movement of planting materials (offshoots) among different countries and localities (Abraham *et al*. 1998).

2) The highly aggregated spatial distribution of RPW (Faleiro *et al*. 2002), this distribution pattern due to the repeated infestation of RPW in and around heavily infested gardens (Faleiro *et al*. 2002). Its Intensive nonhomogenous distribution in the palm or the field (MOEW 2014).

3) The absence of its natural enemies in its new area (MEW 2014).

4) The concealed nature of the pest (it can be hidden in tunnels of 15 to 20 cm deep) (MOEW 2014).

5) RPW females can breed in a wide range of climate conditions because the larvae feed inside their host plants (Ajlan and Abdulsalam 2000),

6) The high capability of females for sperm storage would guarantee the continuation of production of offspring (Kaakeh 2005),

7) The high rate of multiplication (Faleiro *et al*. 1998; Nirula 1956)

8) The larval long period (MOEW 2014),

9) the hardy nature of the crop and the unique agroclimatic conditions which makes detection of infested palms in early stage difficult (Abraham *et al*. 1998, 2001) and

10) The modern date palm farming practices (Faleiro 2006a), in addition neglected and closed gardens have role in the increase of infection (MOEW 2014).

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II MANAGEMENT

13 RISK PREDICTION (RP) AND ASSESSMENT (RA)

Risk prediction and assessment are essential topics to determine the critical control point before recommending and deciding RPW management strategy, furthermore they are essential to evaluate the efficacy of the adopted management program.

Different procedures were used successfully in RPW risk prediction and assessment such as sequential sampling based risk assessment (Faleiro *et al*. 2010), ecological niche modeling (ENM) (Fiaboe *et al*. 2012), palm thermal constant (Mozib and El-Shafie 2013; Salama *et al*. 2002) and the infestation risk (IR) symptoms classes (Pontikakos and Kontodimas 2013).

Temperature. Dembilio *et al*. (2011a) along with Salama *et al*. (2002) demonstrated that the thermal constant could be used to predict the emergence time of the adults to recommend appropriate control procedure. Dembilio *et al*. (2011a) predicted the oviposition and egg hatching periods based on mean monthly temperatures in the Mediterranean basin (Table 14).

Ecological niche modeling (ENM). Fiaboe *et al*. (2012) used the ENM approaches to predict the potential distribution of RPW.

Sequential sampling based risk assessment (SSBRA). Faleiro *et al*. (2010) explained that the SSBRA involved the inspection of palms in sequences in an area of 100 palms/h until determination of the infestation level, accordingly, the area wide management decision is recommended or not. They provided a ready to use decision-making guide for palms.

Infestation risk (IR). IR provides a risk classification for each tree based on symptoms identification key that includes 10 symptoms classes, then the IR percentage is determined (Pontikakos and Kontodimas 2013). See I-10.

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IMPORTANT

See I-6 (temperature) and I-10 (Symptoms) for more details.

See Table (14) for information on the oviposition and egg hatching periods based on mean monthly temperatures in the Mediterranean basin.

14 LOCATION AWARE SYSTEM (LAS))

LAS is a geographical information system (GIS) (Barranco *et al*. 2006; Massoud *et al*. 2011; Pontikakos and Kontodimas 2013; Soroker *et al*. 2013), it applies different techniques to detect, take decision, protect and treat RPW infestation in large areas (Pontikakos and Kontodimas 2013).

LAS comprises: 1) monitoring spatial distribution of palms and RPW, trapping, management actions, management evaluation, 2) decision Support System (DSS) and 3) information sharing.

Data were organized in queries include users, area, palm and trap. DSS of the infestation risk (IR) depends on IR classification that provides a risk classification for each tree based on a symptoms identification key that includes 10 symptom classes, then the IR percentage is determined (Pontikakos and Kontodimas 2013).

The suspected palms by LAS are then inspected by dogs, inspecting crown window, or other methods at a small scale (Pontikakos and Kontodimas 2013; Soroker *et al*. 2013).

Pontikakos and Kontodimas (2013) applied LAS successfully to detect and treat RPW in Greece; it is easy, accurate and effective.

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15 DETECTION AND MONITORING

Early detection of RPW is an essential topic for the success of management procedures, where the palm heart is still healthy and the trunk is still stable. Furthermore, it will prevent the emergence and migration of adult weevils (Carmelo *et al*. 2011; Faleiro 2006a; Faleiro *et al*. 1998; Hallett *et al*. 1999; Mankin 2011; Mozib and El-Shafie 2013; Peri *et al*. 2013; Pontikakos and Kontodimas 2013; Soroker *et al*. 2013). They should be effective, sensitive, specific and rapid (Soroker *et al*. 2013).

Although there are different early detection methods, they are not practical and not adapted to large scale area (Soroker *et al*. 2013).

Early detection methods include visual, acoustic (sound), olfactory (smell) detection either by naked sense organs or by automatic detectors, image processing system, electromagnetic signatures and / or semiochemical-based methods.

The early detection requires the availability of data and information such as palm species, palm location, RPW population characteristics, risk assessment, among others (Barranco *et al*. 2006; Faleiro *et al*. 2010; Massoud *et al*. 2011; Pontikakos and Kontodimas 2013; Soroker *et al*. 2013). These data and information should be available in up to dated version (Pontikakos and Kontodimas 2013).

Image processing based techniques are detection methods that detect either the presence of RPW individuals or the symptoms of infestation.

15.1 VISUAL DETECTION

15.1.1 DETECTION OF RPW INDIVIDUALS

Detection of RPW individuals by naked eyes. RPW individuals could be found in any place within the palm or in the soil (see I-10).

Image processing based techniques-the conclusive algorithm. Al-Saqer and Hassan (2011) proposed a conclusive algorithm for RPW recognition that can be used later to design and develop an efficient RPW wireless automated detection system (wireless image sensor network). They explained that this conclusive algorithm was a combination of regional properties, Zernike moments and rostrum analysis techniques. They observed that it could recognize 97 % of RPW and 88 % of other insects correctly; the processing image maximum time is 0.47 sec.

15.1.2 DETECTION OF EXTERNAL SYMPTOMS

RPW external symptoms can be detected by naked eyes from distance and / or by cutting a window (50-60 cm wide from canopy base to center) at the base of the leaves or palm (Ferry and Gomez 2012; Soroker *et al*. 2013). However, visual detection is not applicable on large scale, it needs experience, it is time consuming, costly and inaccurate (Soroker *et al*. 2013).

15.1.3 DETECTION OF PHYSIOLOGICAL SYMPTOMS

Direct detection of palm temperature. Mozib and El-Shafie (2013) recommended the development of a multi-sensor fusion system based on the temperature differences between the healthy, infected palm and the outside temperature for early detection of RPW at large scale.

Aerial based sensing imaging. Cohen *et al*. (2012) and Soroker *et al*. (2013) reported that aerial thermal imaging using automated procedures could detect the differences in temperature from above, hence mapping the infestation in large area.

Soroker *et al*. (2013) reviewed that the change in temperature could be visualized from above; however, the solar radiation interfered with the thermal image, and the lateral view was prevented accordingly it was not applicable.

Cohen *et al*. (2012) (as cited in Soroker *et al*. 2013) showed that aerial thermal images would be a promising tool to map water status of palms in homogenous plantation on large-area scale. They developed a semi-automated procedure based on the watershed segmentation. Their procedure allowed detection of all palms in the thermal image accurately, as well the extraction of canopy temperature of each palm.

15.2 BIOACOUSTIC DETECTION

RPW presence can be detected with a naked ear when a large number of larvae exist inside the palm (Gutierrez *et al*. 2010). However, at early infestation level, the sound activity is too low to be distinguished by trained naked ear (Soroker *et al*. 2013) so several researchers have proposed different acoustic sensors (Roch *et al*. 2013).

The acoustic activity of RPW could be separated into different sound categories: 1) eating sound from larvae, 2) moving sounds from larvae, and 3) larvae spinning a cocoon sound (Laar 2002).

The acoustic activity of healthy palms could be separated into sharp quick click sounds or long continuous sounds. It tends to decrease within a period of 2-3 min (Pinhas *et al*. 2008).

RPW activity sounds continue for several minutes, they are produced as bursts interspersed by longer silent intervals (Mankin *et al*., 2008). Two types of RPW larval feeding sounds were recorded by digital laser vibrometer:

1) CLICKS or SNAPS: very short pulses (1-4 ms) (Mankin *et al*. 2011), (2-6 ms) (Zorovic 2011), with maximum amplitude at 1-8 kHz (Mankin *et al*. 2011), 2200Hz (Zorovic 2011) and 2) RASPS or BITES: longer pulses lasting for an average of 440 ms (±260) (Mankin *et al*. 2011), (320 ms±90 ms) (Zorovic 2011), fused CLICKS with maximum energy of <3 kHz (some frequency peaks reached up to 16 kHz) and were sometimes repeated very regularly (Mankin *et al*. 2011).

Larval activities were found in a frequency range between 2230 Hz and 2270 Hz, the signal intensity increased, as the number of larvae was higher (Gutierrez *et al*. 2010).

Laar (2002) mentioned that RPW sound activities were very aggressive comparing to other borers. He found that the maximum frequencies were up to 40 kHz but that was not useful in RPW bioacoustic detection as they were not dominant (Laar 2002). The short pulses could be used for the detection purpose (Laar 2002).

Acoustic sensors. Acoustic sensors aim to acquire, transfer, identify, isolate, analyze and parameterize dominant repeated.

Laar system. Laar (2002) was the first to record and separate RPW sound activities (Laar 2002). His detector based on the number and frequencies of positive tones. See Laar (2008) for details on different Laar bioacoustic detection systems.

Laar (2002) inserted an acoustic probe in the palm trunk to improve the capture of RPW sounds, then, the sensor device analyzes the captured sound in real-time, supplying an audible tone (Laar 2002).

The Laar system is a high sensitive bioacoustic detection system, it is used successfully in RPW detection (Laar 2008), and as well it was easy (Laar 2002). However, it is difficult to separate single pulses with RPW as the produced sounds are collection of many pulses (Laar 2002).

Gutierrez *et al*. (2010) proposed a device that based as Laar system (Laar 2002) on the number and frequency of the positive tones, instead of audible tones it works by activating a blinking red LED to detect the presence of RPW (See Rach *et al*. 2013 for references). This device can detect the presence of two week old larvae and RPW presence in palms infested with only 5 individuals under controlled conditions with sound intensity around 2250 Hz, it does not require training, and its results are not affected by the background of other insects as they produce different frequencies (5-7 kHz) (Gutierrez *et al*. 2010). However, more experiments should be undertaken to assess the level of infestation.

The signal processing system. Husssein *et al*. (2009, 2010) along with Potamitis *et al*. (2009) proposed an acoustic detector that detects RPW larval sounds using signal processing analyses that allow rapid changing of amplification levels. It detects the presence of RPW depending on a particular set of signal features such as signal roll-off, slope and temporal spread, and tuning processing parameters as optimum frame size and proper window functions (Husssein *et al*. 2009, 2010; Potamitis *et al*. 2009). They identified some spectral and temporal features of RPW sound activity such as the sound impulse bursts from RPW feeding activities to distinguish them from other background sounds.

This system detects RPW with accuracy rate of 99.1 %, and distinguishes between the signals produced near the sensor from those produced away. However, it is expensive, need training and not specific (Potamitis *et al*. 2009).

The portable digital lazer vibrometer. Mankin *et al*. (2011) along with Zorovic (2014) proposed a portable digital laser vibrometer recording made by digital laser vibrometer. In their system, a laser vibrometer (a non-contact) microphone is used to overcome the problem of attaching a microphone to a soft tissue (Mankin *et al*. 2011).

A portable digital lazar vibrometer (a non-contact acoustic sensor) is very sensitive, robustness, its frequency ranges from 0 to 22 kHz, it does not need to attache a microphone to the palm soft tissue as it works from distance (up to several meters). It is comparable or superior to other acoustic sensors (Mankin *et al*. 2011; Zorovic 2014) and can be applied for wide scale area management (Zorovic 2014).

Mathematical method. Pinhas *et al*. (2008) proposed bioacoustic detection system that based on speech recognition-based algorithm for automatic detection. Their system is applied using clustering algorithm (Vector quantization (VQ) or Gaussian mixture modeling (GMM)).

This system can detect RPW with 98.9 % accuracy under optimal conditions. However, it needs to be repeated under natural conditions (Pinhas *et al*. 2008); it is feasible, simple and easy to be used with non trained person.

The on-line portable acoustic device. Siriwardina (2010) proposed an on-line portable acoustic device that produces a clip sound of RPW activity. It applies an active band pass filter in the RPW effective frequency range (800–2.500 Hz frequency band).

This device can detect RPW with 97 % accuracy with sounds gathered at four different points in each palm.

The autonomous wireless sensor. Rach *et al*. (2013) proposed an autonomous wireless bioacoustic sensor.

This sensor is physically installed in each palm under suspect. It is operated by long live battery (more than one year). It can identify, analyze RPW audio signals, and then send alerts wirelessly to a central station, the station send alarm allowing the supervisor to take decision for a large area management (Rach *et al*. 2013).

This device can performe autonomous continuous monitoring with 90 % detection accuracy in large areas and reduced significantly the overall monitoring costs and the detection delay (Rach *et al*. 2013).

Advantages of bioacaustic methods. Acoustic methods are applicable and can be used in the early detection of RPW infestation (Fiaboe *et al*. 2011; Laar 2008; Mankin 2011), optimize the preventive operation (Laar 2008), assess the success of pesticide treatment (Fiaboe *et al*. 2011; Laar 2008), and reduce the quarantine time from several months to four weeks (Laar 2008; Soroker *et al*. 2013).

Bioacoustic sensors were used successfully to detect RPW larvae in offshoots (Hetzroni *et al*. 2004; Soroker *et al*. 2004), in coconut palm trees (Siriwardena *et al*. 2010) and to detect pupae in soil (Mankin *et al*. 2000). As well, infestations near the crown can be detected from distances up to 4 m (Mankin *et al*. 2011). 94 % of infected trunk can be detected in quarantine (Hussein *et al*., 2010).

The low RPW signal frequency can be distinguished from the high background (3.4 and 6 kHz) (Fiaboe *et al*. 2011). Also, if the background noises are not over powering, they can be distinguished from RPW sounds by training (Fiaboe *et al*. 2011).

Disadvantages of bioacaustic methods. Acoustic technology is not commonly used in RPW detection (Mankin 2011) due to some limitations such as:

1) it is difficult to detect the presence of young larva or silent stages (eggs and pupae),

2) it is difficult to distinguish RPW larval sounds from other background sounds (Jolivet 1998; Mankin, 2011) either inside or outside the palm (Mankin 2011),

3) it is not possible to be applied for large-scale plantation,

4) it is time, labor and cost consuming (Rach *et al*. 2013), and

5) The monitoring process is not continuous (Rach *et al*. 2013).

15.3 ELECTROMAGNETIC SIGNATURE

Masress (2010) reported that the Egyptian armed forces have been invented a RPW detector that based on the electromagnetic signature of RPW. The detector showed promising results in some area, however it is not applicable in a large-scale area, also it needs more research to be developed.

15.4 MONITORING

See chapter 19 for information on mass trapping.

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IMPORTANT

See section I-6 for information on temperature, and section I-10 for information on RPW Symptoms

16 CULTURAL CONTROL

The aim of cultural control is to create a non-suitable environment for the feeding and multiplication of the pest.

16.1 TRAINING AND EDUCATION

Regular training and education concerning RPW infestation, prevention, and early detection and treatment methods for farmers play an important role in combating the pest (Abraham *et al*. 2001).

16.2 LEGISLATIVE CONTROL

Movement of infected palms among and within countries should be organized and controlled (Faleiro 2006a; Soroker *et al*. 2013).

16.3 LIGHT TRAPS

Light traps are used to control the palm pests that facilitate the RPW infestation such as fruit stalk borer (*Oryctes elegans*, Coleoptera: Scarabaeidae) and the longhorn date palm borer (*Pseudophilus testaceus*, Coleoptera: Cerambycidae) (Lokma and Alquait 2002). One light trap for each 500 palms is recommended (MOEW 2014).

16.4 PHYTOSANITARY

Neglected and closed gardens have an important role in the increase of RPW infection (MOEW 2014). Sanitation should be done in any area where the palms exist either as a major plantation or surrounding other plantations (USDA 2011). The procedures that are involved in the sanitation include: treat palm from any disease or injuries caused by other pests, cut and burn damaged tissues or palms and achieve agricultural methods as appropriately (The Alameda 2008; MOEW 2014; USDA 2011).

16.5 AGRICULTURAL METHODS

16.5.1 PRUNING

Time of pruning. Performing the pruning and other management practices is recommended in winter under the Mediterranean climate (Dembilio *et al*. 2011a; Hussain *et al*. 2013; The Alameda 2008) where the mortality of eggs and immature stages are high (Dembilio and Jacas 2011). In contrast, Ferry and Gomez (2012) observed that the pruning wounds will not allow the oviposition of RPW adults that will be attracted to the emerged volatiles from these wounds. Accordingly, they suggest doing any process as it is required not wait to certain season, as the delay of pruning to winter will delay the early detection of RPW infection.

Where to cut? Cutting date palm green leaves 120 cm from their base is recommended (Alhudaib 2009).
The green leaves of coconut palms should be cut at, or beyond the region of the leaflets emergence at the base; the remaining basal portions of the leaves dry and become unsuitable for larval development (larvae hatched from eggs laid at the cut ends of the leaves); hence the hatched larvae will not be able to continue their way into the trunk (Abraham 1971).
Treating pruned palms. The pruned palms should be treated by insecticide to avoid any further infestation (Ferry and Gomez 2012; El-Lakwah *et al*. 2011). Although several authors recommend filling the pruning wounds, Ferry and Gomez (2012) do not recommend so as the pruning wounds will not allow the oviposition of RPW adults that will be attracted to the emerged volatiles from these wounds.

16.5.2 IRRIGATION

Flooding irrigation increases the RPW infestation level compared to dripping irrigation (Al-Ayedh and Rasool 2009; El-Lakwah *et al*. 2011; Krishnakumar and Maheswari 2003), this may due to the suitable habitat to RPW that is created by flooding irrigation by increases soil moisture and the relative humidity (RH) (Al-Ayedh and Rasool 2009; Aldryhim and Al-Bukiri 2003) and allowing the growth of grasses in high density (Aldryhim and Al-Bukiri 2003). This habitat facilitates trunk penetration by larvae, egg lying (Al-Ayedh and Rasool 2009; Krishnakumar and Maheswari 2003), egg hatching and mating behaviour (Al-Ayedh and Rasool 2009).

16.6 MECHANICAL METHODS

Elimination of the damaged parts at the correct time will recover the palm as its heart and stem are still alive and stop the pest dispersion (Ferry and Gomez 2012). Theses methods involve:
1) removing the dry and infested parts of the palm, until the undamaged fibers, spray pesticide then cover the peeled area with clay (The Alameda 2008), and
2) removing the severely infested palms from the roots, cutting them into pieces, burned, and buried (Aldryhim and Al-Bukiri 2003; Ferry and Gomez 2012; Murphy and Briscoe 1999; Rajapakse *et al*. 1998; The Alameda 2008) in an isolated area, 1.5-2 m in depth.
These methods need to be done under special conditions (Laar 2004b).
The disadvantages of removing the infested palm due to: 1) cut trees are biologically active up to more than one year after removing due to the high humidity of palms, the cleaning of soil with insecticides isn't enough, because eggs could survive and the remaining root rests are most enough food for some larvae (Laar 2004b), 2) transporting infested trees for burning introduces the weevil to new areas (Hallett *et al*. 1999), 3) burning of the palm trunk is often incomplete as the external surface of the palm protects the internal structure of the palm (Laar 2004b), so that larvae and pupae survive and complete development (Hallett *et al*. 1999).

16.7 BURNING

Burning the palm foliage do not kill RPW stages in the trunk, so palms in late stage of infestion should be uprooted, splitted open then burned (Alhudaib 2009; Soroker *et al*. 2005). Burning of the palm trunk is often incomplete as the external surface of the palm protects the internal structure of the palm, and also (Laar 2004b), so that larvae and pupae survive and complete development (Hallett *et al*. 1999).

16.8 MICROWAVE (MW) TREATMENT

Microwave heating (MW) is proposed as a promising approach in IPM program against RPW (Ali and Al-Jabr 2003; EPPO 2011; Massa *et al*. 2013). It is a non-ionized radiation, dielectric heating that Kills RPW inside the palm by increasing the internal temperature of palm tree to the lethal temperature of RPW (Massa *et al*. 2013).

The efficacy of MW heating depends on the dielectric behavior (dielectric constant & loss factor) of the treated subject (Massa *et al*. 2013). The dielectric constant is associated with the capability of energy storage in the electric field of the material (Massa *et al*. 2013).

The loss factor is associated with the conversion of electric energy to heat energy in the material (Massa *et al*. 2013). Regarding the dielectric properties, *Phoenix canariensis* trunk differs from other palm trunks in its high loss factor either in healthy or infested palm. This high loss factor due to the high water content, it reduced with the reduction of water content. It implies high power loss and a low penetration depth of microwave into the trunk because most of the energy is converted in the first layer of the trunk.

MW kill all stages after 5 min/80 °C and 30 min/50 °C, the lethal exposure time is in linear relation with the RPW weight, adults or larvae of 2 to 4 g need 20 min/50 °C (Massa *et al*. 2013).

MW may used as Protection, treatment and/or disposition approach of palm (Massa *et al*. 2013).

It is effective as it causes high mortality rate (100%/4.5cm from the palm edge) (Ali and Al-Jabr 2003), it reduces the use of pesticide thus protect the environment (Ali and Al-Jabr 2003; EPPO 2011; Massa *et al*. 2013), and kill all stages and population (Massa *et al*. 2013).

Ecopalm is a device that is used in MW heating treatment, it is environmentally friendly, safe, fast, mobile, easily transportable, and 100 % efficient, in addition, the ECOPLAM RING can be used as preventive and curative tool while the ECOPALM BOX can be used for removing the unrecovered palms (Melli 2009).

As a preventive method ECOPALM can be used to disinfect and help to heal fronds after pruning, this process takes 20 m/palm with preventive effect that lasts for one year (Melli 2009). As a treatment method ECOPALM can eradicate RPW inside the palm at any stage of infestation, this process takes 40m/palm with preventive effect that lasts for one year (Melli 2009). At the serious stages of infestation where the infected palm cannot be recover, the ECOPALM BOX is used first to disinfect the palm then remove it to be transported as a green not infested waste (Melli 2009).

16.9 BIOLOGICAL CONTROL

See II- 17 for details.

16.10 MALE STERILIZATION

See II-18 for details.

16.11 COMBINATION OF IRRADIATION AND ENTOMOPATHOGENS

A new approach to improve the biological control method, in which irradiated male used as a vector of RPW pathogens (Liacer *et al*. 2013). Liacer *et al*. (2013) tried it in a semi-assay field where they used gamma irradiated males infected with the entomopathogenic fungus *Beauveria bassiana* (Ascomycota: Clavicipitaceae), the combination succeeded to reduced the number of immature stages, the female showed post-mortem hyphal growth.

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IMPORTANT

See section I-4 and I-5 for information on natural host range and alternative feeding materials respectively.

17 BIOLOGICAL CONTROL

A wide range of RPW natural enemies were reported from several countries. These agents showed efficacy against RPW in the laboratory however, most of them were not applicable in the field (Abbas *et al*. 2001; Faleiro 2006; Gindin *et al*. 2006; Murphy and Briscoe 1999; Salama *et al*. 2004).
The application of biopesticide depends on the RPW presence and density, as well the time needed by the agent to make infection and the optimal environmental condition (Alhudaib 2009).
Murphy and Briscoe (1999) encouraged the spread of RPW natural enemies on the ground around palms as a protective method.

17.1 BACTERIA

The effectiveness and consistent control of RPW using bacteria in the field was not proved, this may due to the host defense (Manachini *et al*. 2009). Here are some examples about the tested bacteria:
Banerjee and Danger (1997) reported that *Pseudomonas aeruginosa* was not promising as biocontrol agent. The treated larvae required 6 to 8 days after treatment, in case of forced and wading feeding, respectively.
Salama *et al*. (2004) reported that *Bacillus sphaericus* (strain 73) was the most active compared to *B. megaterium* (strain 15) and *B. laterosporus* (strain 27), the suspension of the three strains caused 40 to 60 % mortality of the second larval instar in the laboratory.
Manachini *et al*. (2009) reported that the commercially available *B. thuringiensis* showed pathogenicity at high dose when added to RPW larval diet. They also mentioned that this bacterium produced toxins in form of crystals.

17.2 FUNGI

Entomopathogenic fungi (EPF) are proved efficient against eggs, larvae and adults of RPW (Gindin *et al*. 2006). However, the concealed nature of RPW makes its control by the entomopathogenic fungi a difficult task under natural conditions (Al-Maine and Alkanhal 2004; Faleiro 2006a, 2006b; Wattanapongsiri 1966).
The contact of EPF infects the host, after germination, the conidia penetrate through the host cuticle, after killing, conidia sporulate the cadaver that helps to spread the fungal inoculum to healthy individuals (Hussain *et al*. 2013a, 2013b)
The Alameda (2008) recommended applying fungi on the highly infected palm trees.
El-Bishry *et al*. (2000) tested five EPNs belonging to Rhabditida against RPW. They mentioned that the washing and sterilization of the palm tissues reduced the host finding ability of the juveniles. Their results showed an inhibitory effect of fungi on RPW.

Beauveria bassiana

Dembilio *et al*. (2010a) mentioned that the infection of RPW by *B. bassiana* showed symptoms in three to five days post inoculation. These symptoms included the appearance of abundant hypha between the mouse and the fronds region (in two days), the appearance of hypha from several parts of the adult body and the presence of intercalary aspersoria on the adult head, this later symptom might due to attempts of fungus penetration (Dembilio *et al*. 2010a).

Guerri-Agullo *et al*. (2010) mentioned that the spines, microfolders, and sensilla able to acquire the conidia of *B. bassiana*.

Dembilio *et al*. (2010a) reported that the infection could be transmitted from one sex to the other with 55 to 60 % rate of transmission for male-to-female and female-to-male respectively.

Saleh *et al*. (2004) reported that *B. bassiana* could persist more than 16 days but in low density. They also reported that adult mortality decreased from 100 to 6.7 % at the first and the 16^{th} day respectively.

Gindin *et al*. (2006) reported that *Metarhizium anisopliae* showed more virulence compared to *B. bassiana*.

B. bassiana relatively took longer time to achieve 100 % mortality. It reduced significantly RPW fecundity (up to 62.6 %) and egg hatching (32.8 %), increased larval mortality (30-35 %) in larvae obtained from eggs obtained from treated parents causing 78 % progeny reduction (Gindin *et al*. 2006).

Semi-field preventive assays on *Phoenix canariensis* (5-year old), confirmed the potential of *B. bassiana* as a biological control agent against RPW with efficacies up to 85.7 % (Gindin *et al*. 2006).

El-Sufty *et al*. (2007) reported that the oil formulation of *B. bassiana* caused 13.7-19.2 % adult mortality, while dust formulation caused 8.9 % adult mortality.

Guerri-Agullo *et al*. (2011) reported that *B. bassiana* solid formulation showed high RPW mortality (70-85 %).

Metarhizium pingshaense

Gindin *et al*. (2006) reported that *M. anisopliae* showed more virulence compared to *B. bassiana*.

M. anisopliae caused 80 % egg mortality, 82 % hatched larva mortality, 100 % larval mortality in six to seven days and 100 % adult mortality in two to three weeks. In addition, treated adults had a shorter oviposition period and three times lower fertility than the controls (Gindin *et al*. 2006).

Cito *et al*. (2014) identified and compared two strains of *M. pingshaense*; the two strains produced toxins and protease that degrades cuticle, the two strains showed differences in their virulence, toxicological and enzymatic profiles.

17.3 Mites

Longo and Ragusa (2006) (as cited in Mazza *et al*. (2011)) mentioned that RPW was associated with several species of mites belonging mainly to suborder Uropodina.

Longo *et al*. (2009) (as cited in Mazza *et al*. (2011)) mentioned that RPW–mite association could occur before the adult emergence, as mites were detected on pupae.

Mazza *et al*. (2011a) observed that mites used the weevils as carriers; as well they used their protein. They observed also that the mites rest under the first pair of RPW wings.

Calmerodai deutonymphs

Mazza *et al*. (2011a) observed that *C. almerodai deutonymphs* was highly distributed in all RPW samples from Central and Southern Italy, where it was present in individuals of each tested population (from > half to 100 % individuals of each population). They mentioned the necessity to revise the life history of *Centrouropoda*.

Centrouropoda almeorodai

Longo *et al*. (2009) (as cited in Mazza *et al*. (2011)) supposed that *C. almerodai* attacked RPW pupae as they detected it on 86 % of the examined pupae.

Longo and Ragusa (2006) along with Ragusa *et al*. (2009) (as cited in Mazza *et al*. (2011)) considered a phoretic relationship between *C. almerodai* and RPW. They also referred to the poor available information on the life history traits of this mite species.

Atakan *et al*. (2009) (as cited in Mazza *et al*. (2011)) explained that mites clustered in high number attaching themselves with pedicels to the weevils under the elytra, which might affect the flight behavior of RPW.

Mazza *et al*. (2011a) reported that the laboratory control of RPW using *Centrouropoda almerodai* deutonymphs resulted in 57 to 95 % mortality and reduced the life span of RPW by one-third. They observed that RPW life span decreased in trapped weevils than weevils on plant; however, Atakan *et al*. (2009) (as cited in Mazza *et al*. 2011a) observed the contrary when studied Uropodina. Accordingly, Mazza *et al*. (2011a) recommended the investigation of this issue.

Rhynchopolipus rhynchophori

Abdullah (2009b) reported that *Rhynchopolipus rhynchophori* (Ewing) (Acarina: Podapolipidae) decreased RPW stages in two weeks. He also mentioned that there was a negative relation between the number of mites and pupal weight. Abdullah (2009b) observed that Mites kill their victims by sucking the body fluid.

17.4 NEMATODES

Hussain *et al*. (2013) mentioned that the two insect obligatory parasites nematodes families, Heterorhabditidae and Steinernematidae received the most attention as RPW biological control agents. Abbas (2010) attributed this to their wide host range, their safety, their ease to be produced and applied in laboratory, their associated mutualistic bacteria in the intestine, (*Xenorhabdus* in Steinernematidae and *Photorhabdus* in Heterorhabditidae). In addition, they are highly virulent, killing their host victims within 24-48 h.

EPNs enter their hosts either through inter-segmental membranes or through natural body openings and can spend several generations inside the host (Dowds and Peters 2002). They decompose their host (Chavarria-Hernandez *et al*. 2007), the dead RPW decreased between 14 to 28 days, also no nematode was found in dead female (Liacer *et al*. 2009), due to the fact the EPN leave its host once it died (Ehlers 2001).

Although Garcia del Pino (2006) and Gaugler (2007) consented that *Steinernema* spp. is a classic ambusher, Liacer *et al*. (2009) along with Elawad *et al*. (2007) observed that (the infective third juvenile stage / dauer juvenile or DJ) it did not stay outside the palm but penetrate the crown looking for and infecting RPW.

The bacterial symbionts *Photorhabdus* sp. and *Xenorhabdus* sp. are associated with Heterorhabditidae and Steinernematidae respectively, where they exist in their intestine, in the bacterial receptacle (modified part of the intestine (Snyder *et al*. 2007).

Time of application. Liacer *et al*. (2009) recommended the application of the EPNs before the main two flight periods in the Mediterranean region (April-May and September-October). They explained that the application in such periods could protect the palm as it would attack adults before oviposition, new emerged larvae from the new generation and immature stages from old generation.

The Alameda (2008) recommended the use of nematodes from May to October (20-30 M/every 45 days).

Pathogenicity

A dose of 25–50 IJs / cm2 of soil surface was recommended against RPW (Georgis and Hague 1991). The percentage of parasitized RPW by the nematode increased between two to four weeks after release (Dillon *et al*. 2006; Garcia del Pino 2006; Gaugler 2007; Liacer *et al*. 2009) due to the time taken by the nematode to find RPW and the time taken by RPW to be infected (Liacer *et al*. 2009).

Dembilio *et al*. (2010b) along with Liacer *et al*. (2009) concluded that the observed differences in efficacy between different experiments may due to the different applied doses or the use of the nematode alone without the complex nematode-chitosan.

The concealed nature of RPW larvae (Abraham *et al*. 2002; Danger 1997), the high temperature, the amount of frass, and the acetic acid and ethyl acetate generated by RPW inside the palm inhibit the EPNs (Monzar and El-Rahman 2003).

Heterorhabditis* and *Steinernema

Abbas and Hanounik (1999) tested the pathogenicity of *Heterorhabditis* sp. (Egyptian isolate) against larvae and adults of RPW. They reported that:
1) the RPW larval mortality (at concentration of 30 to 240 infective juveniles (IJs / larva) ranged from 10-100 %,
2) the LC50 value against RPW larvae was 56.6 IJs per larva,
3) RPW adults were less susceptible than RPW larvae,
4) the LC50 value against RPW adults was 1.416 IJs per adult. Those infected adults produced 2.000–242.000 IJs per weevil, and
5) there was no correlation between dose and IJs production.

Shamseldean (2002) tested the virulence of 13 species and/or isolates of the *Heterorhabditis* and 2 isolates of *Steinernema* against RPW larvae, pupae and adults. They found that RPW adults were the most susceptible stage while the last instar larva was less susceptible than the pupa.

Shamseldean and Atwa (2004) tested the virulence of three Egyptian isolates of *Steinernema* against RPW larvae and adults. They found 100 % RPW adult mortality rate, while they obtained 78 to 90 % RPW last larval instar mortality rate.

Shamseldean (2002) along with Shamseldean and Atwa (2004) reported that the injection of the Egyptian strains of nematode suspension in palm trunk resulted in 77.7 and 77.1 % recoveries using *H. bacteriophora* (strain EKB20), 88.9 and 91.9 % recoveries using *H. indicus* (strain EGBB) and 83.3 and 72.2 % recovering using *Steinernema* sp. (strain EBNUE)) after one month of treatment.

Hanounik (1998) reported that *Steinernema* and *Heterorhabditis* showed 100 % and 50 % larval mortality in the laboratory and in the field trials respectively.

Abbas *et al*. (2001a, 2001b, 2001c) observed a presence of a slight difference in virulence between *S. abbasi* and *H. indicus* (at concentrations of 12.5 and 25 IJs/cm2 of sand surface) against RPW adults. However, they did not notice any difference at concentrations of 50 and 100 IJs/cm2.

H. bacteriophora

Saleh and Alheji (2003) tested the pathogenicity of *H. bacteriophora* HP88 from USA against RPW adults and the 3^{rd} and 8^{th} RPW larval instars, in laboratory. They used a concentration of (100 IJs per larva) for the assay with larvae, whereas concentrations of (10–100 IJs/cm2 of sand surface were used for adults), their results showed that:
1) the 3^{rd} larval instar was highly susceptible, where 100 % mortality was obtained within 2–3 days,
2) the 8^{th} larval instar was less susceptible, where 70 % mortality was obtained,
3) the LC50 value was 40.2 IJs/cm2 of sand, and
4) the RPW adults were less susceptible than the RPW larvae. The mortality percentage ranged from 25-83 %, and
5) the LC50 value was 2.555 IJs.

H. indicus

Abbas *et al*. (2001b, 2001c) reported that:

1) the 3rd larval instar was more susceptible to the nematodes *H. indicus* infection than the 5th one, at concentrations of 100 and 200 IJs/larva,

2) the LC50 values of *H. indicus* against 3rd and 5th instars were 123 and 128.8 IJs/larva, respectively,

3) 8.6 % (average no of IJs/larva: 35,000 (5.000–85.000)) of dead RPW larvae produced IJs when infected with *H. indicus*,

4) the LC50 value of *H. indicus* was 25.1 IJs/cm2 of sand against RPW adults, and

5) 89 % (average no of IJs/adult: 776,000 (145.000–2.820.000) of dead RPW adults produced IJs when infected with *H. indicus*, at concentration of 100 IJs/cm2 of sand.

Saleh and Alheji (2003) tested the pathogenicity of *H. indicus* from KSA against RPW adults and the 3rd and 8th RPW larval instars, in laboratory. They used a concentration of (100 IJs per larva) was used for the assay with larvae, whereas concentrations of (10–100 IJs/cm2 of sand surface were used for adults), they found that:

1) the 3rd larval instar was highly susceptible, where 100 % mortality was obtained within 2–3 days,

2) the 8th larval instar was less susceptible, where 70 % mortality was obtained,

3) the LC50 values was 49.9 4 IJs/cm2 of sand,

4) the RPW adults were less susceptible than the RPW larvae. The mortality percentage ranged from 17-75 %, and

5) the LC50 value was 3.172 IJs per RPW adult.

Elawad *et al*. (2007) found a substantial decline in RPW population when controlled by *H. indicus* (isolate from UAE) (4 million infective dauer juveniles) in mid-March and mid-April / in KSA.

Praecocilenchus ferruginophorus

Rao and Reddy (1980) recorded *P. ferruginophorus* (Aphelenchida) parasitizing RPW adults in India. They observed that the size of the detected nematodes in the haemocoel ranged from small intrauterine to large mature females. Accordingly, they suggested the presence of several simultaneous and unsynchronized life cycles of that nematode in RPW.

S. abbasi

Abbas *et al*. (2001a, 2001b, 2001c) observed that *S. abbasi* was effective in laboratory while it showed inconsistent results in the field.

Abbas *et al*. (2001b, 2001c) reported that:

1) the 3rd larval instar was more susceptible to the nematodes; *S. abbasi* infection than the 5th one, at concentrations of 100 and 200 IJs/larva,

2) the LC50 values of *S. abbasi* against 3rd and 5th instars were 69.2 and 97.7 IJs/larva, respectively,

3) 11.5 (average no of IJs/larva: 33.000 (2.000–113.000)) of dead RPW larvae produced IJs when infected with *S. abbasi*,

4) the LC50 value of *S. abbasi* was 23.2 IJs/cm2 of sand against RPW adults, and

5) 93 (average no of IJs/adult: 983.000 (93.000–3.055.000))) of dead RPW adults produced IJs when infected with *S. abbasi*, at concentration of 100 IJs/cm2 of sand.

Saleh and Alheji (2003) tested the pathogenicity of *S. abbasi* from Oman against RPW adults and the 3rd and 8th RPW larval instars, in laboratory. They used a concentration of (100 IJs per larva) for the assay with larvae, whereas concentrations

of (10–100 IJs/cm2 of sand surface were used for adults). Their result revealed that:
1) the 3rd larval instar was highly susceptible, where 100 % mortality was obtained within 2–3 days,
2) the 8th larval instar was less susceptible, where 60% mortality was obtained,
3) the LC50 value was 32.4, IJs/cm2 of sand,
4) the RPW adults were less susceptible than the RPW larvae. The mortality percentage ranged from 33-75 %, and
5) the LC50 value was 2.060 IJs per RPW adult.

S. carpocapsae

Abbas and Hanounik (1999) tested the pathogenicity of *S. carpocapsae* (All strain) against larvae and adults of RPW, they reported that:
1) the RPW larval mortality (at concentration of 30 to 240 infective juveniles (IJs)/larva) ranged from 10-100 %,
2) the LC50 value against RPW larvae was 61 IJs per larva,
3) RPW adults was less susceptible than RPW larvae,
4) the LC50 value against RPW adults were 1.100 IJs per adult. Those infected adults produced 2.000–242.000 IJs per weevil, and
5) there was no correlation between dose and IJs production.

Saleh and Alheji (2003) tested the pathogenicity of *S. carpocapsae* from Germany against RPW adults and the 3rd and 8th RPW larval instars, in laboratory. They used a concentration of (100 IJs per larva) for the assay with larvae, whereas concentrations of (10–100 IJs/cm2 of sand surface were used for adults), their result revealed that:
1) the 3rd larval instar was highly susceptible, where 100 % mortality was obtained within 2–3 days,
2) the 8th larval instar was less susceptible, where 80 % mortality,
3) the LC50 value was 6.4 IJs/cm2 of sand,
4) the RPW adults were less susceptible than the RPW larvae. The mortality percentage ranged from 33-92 %, and
5) the LC50 value was 406 IJs per RPW adult.

Saleh *et al*. (2004) reported that *S. carpocapsae* adult mortality decreased from 66.7 to 11.1 % at the first and fourth day respectively.

Although the application of *S. carpocapsae* was effective against RPW (Dembilio and Jacas 2013; Dembilio *et al*. 2009b; Ferry and Gomez 2012; Liacer *et al*. 2009), it needed to be repeated each month (Ferry and Gomez 2012).

Llácer *et al*. (2009) reported 80 and up to 98 % efficacy of *S. carpocapsae* (Steomer Biorend R®) against all RPW stages, for the curative and preventive treatments respectively. This nematode formulation could persist in the palm palm for 2 weeks; accordingly Llácer *et al*. (2009) recommended to be repeated every 2 to 3 weeks.

Manachini *et al*. (2013) observed that there was a positive relationship between RPW mortality and both the dosage and the time of exposure to *S. carpocapsae*. They mentioned that this nematode affected the larval weight and caused the decrease of the number of the larval hemocytes after 24 h. In addition, they reported that it was not encapsulated with the RPW hemocytes.

***S. carpocapsae* and imidacloprid**

Dembilio *et al*. (2009b) compared between *S. carpocapsae* (chitosan WG (SteomerBiorend R®) and the systemic insecticide imidacloprid. They found that 1) the efficacies of both the nematode formulation and the insecticide were equivalent, 2) their efficacies did not significantly change when used together and 3) the

nematode application was more laborious than the pesticide

S. riobravis

Abbas and Hanounik (1999) tested the pathogenicity of *S. riobravis* (Egyptian isolate) against larvae and adults of RPW. They reported that:

1) the RPW larval mortality (at concentration of 30 to 240 infective juveniles (IJs)/larva) ranged from 10-100 %.

2) the LC50 value against RPW larvae was 51 IJs per larva.

3) RPW adults were less susceptible than RPW larvae

4) the LC50 value against RPW adults was 900 IJs per adult. Those infected adults produced 2.000–242.000 IJs per weevil.

5) there was no correlation between dose and IJs production.

Synergistic materials. Different synergistic additives such as antidesiccants (Hanounik *et al*. 2000; Georgis 1990; Kaya and Gaugler 1993), chitosan formulation (Dembilio *et al*. 2010b; Liacer *et al*. 2009) and symbiont bacteria (Liacer *et al*. 2009) were used with nematode suspension in the field to enhance their persistence and performance.

Abbas *et al*. (2000) added different commercial antidesiccants such as Leaf-Shield (Aquatrols Corporation of America) (a rate of 2.5 g/l), and Liqua-Gel (Miller Chemicals and Fertilizer Corporation, USA) (a rate of 100 ml/l) to the nematode suspension (*S. riobravis*) against RPW. They sprayed the palm trunks (3 to 5 years old palm) with a quantity of nematode suspension (2×10^6 IJs per tree) enough to wet the trunk. They released RPW individuals 3 h post treatment. Their results showed 8.9 % and 13.3 % RPW adults' mortality with Leaf-Shield and Liqua-Gel respectively, comparing to 11.7 % RPW adults mortality w hen nematode suspension was sprayed without antidesiccants. They mentioned that 40 % of the dead RPW were found on the trunk at leaf-axils.

Abbas (2010) explained the poor efficiency of attributed to the adverse effect of sun heat and UV radiation on the IJs. The leaf-axils of palm trees do not provide enough shade or shelter to IJs. In addition, soil, not leaf-axils, is the natural habitat for the nematodes.

Hanounik *et al*. (2000) did the same experiment as Abbas *et al*. (2000) against *Heterorhabditis* sp. (KSA isolate). They released RPW individuals before the spraying process (a rate of 3.75 X 10^6 IJs in 3 l of water per tree). Their results showed 87.5 % and 65 % RPW adults' mortality with Leaf-Shield and Liqua-Gel respectively, comparing to 65 % RPW adults mortality when nematode suspension was sprayed without antidesiccants.

Abbas (2010) explained the different efficiency obtained by Abbas *et al*. (2000) and Hanounik *et al*. (2000) to the difference in experiment procedures.

Saleh and Alheji (2003) did similar trial as Abbas *et al*. (2000) and Hanounik *et al*. (2000) against *S. carpocapsae* and *H. bacteriophora* (a rate of 2 X 10^6 IJs in 3 l of water per tree) (daily mean temperature between 8 and 20 °C). Their results showed 77.5 % and 17.5 % in RPW adults using S. *carpocapsae* and *H. bacteriophora* respectively.

Abbas (2010) attributed the low efficacy of *H. bacteriophora* in this experiment to the change in environmental conditions as *H. bacteriophora* was isolated from a tropical area and it was not adapted to low temperatures in the experiment area (Abbas 2010).

Dembilio *et al*. (2010b) along with Liacer *et al*. (2009) reported that *S. abbasi* in a chatoyant formulation showed efficacy ranged from 83.8 to 99.7 % (Dembilio *et al*. 2010b) and 80 % (curative assay) to 98 % (protective treatment) against all stages of RPW (Liacer *et al*. 2009). These efficacies were higher than those obtained from the application of *S. abbasi* alone (Abbas *et al*. 2001a, 2001b, 2001c) and from chemical pesticides (Liacer *et al*. 2009).

Dembilio *et al*. (2010a) reported that the combination of *S. carpocapsae* and imidacloprid in chitosan formulation had a synergistic effect on the efficacy against RPW under field conditions. This combination decreased the reproductive potential of the RPW, accordingly, it was recommended as preventive procedure each 60 days (Tapia *et al*. 2011).

Abdel-Razek *et al*. (2004) reported that the infection of RPW larvae with the complex nematode-bacterial *H. bacteriophora-Photorhabdus luminescens* (*HbPl*) and *S. carpocapsae-Xenorhabdus nematophilus* (*ScXn*) resulted in different biochemical effects on the lymph and body fat.

In the infected RPW hemolymph, the total amino acids composition decreased by 65.67 % (2.5 folds) in case of the complex *HbPl* and by 62.5 % (5.3 folds) in case of the complex *ScXn* while it decreased by two folds in body fat for both complexes.

The carbohydrate composition was higher in the infected hymolymph than the healthy one, while the lipid was lower. The authors explained that may due to the reaction of larvae to infection as it use the lipid to produce an enzyme to overcome the infection. The change in protein composition due to infection may result in reduction in larval weight, slow development, degeneration of the tissues and prevention of adult emergence.

Place of application. Abbas *et al*. (2000) observed that the application of the EPN around the palm resulted in 33-87 % adult mortality, while spraying the palm trunk resulted in 8-13 % adult mortality.

Methods of application

Injection. Several researchers tried the nematode injection into palm trunk either by making holes in the trunk where the brownish juice appeared (symptom) (Abbas *et al*. 2001a; El-Bishry *et al*. 2000; Shamseldean 2002; Shamseldean and Atwa 2004) or by pouring the nematode suspension in the larval entry holes (Abbas *et al*. 2000) or by making holes in the infestation holes reach the tunnel network in the stem (Saleh and Alheji 2003).

Some researchers found the nematode suspensions injection (*H. bacteriophora* (strain EKB20), *H. indicus* (strain EGBB) and *Steinernema* sp. (strain EBNUE)) was efficient (Shamseldean 2002; Shamseldean and Atwa 2004) while other found negative or low efficient results (*abbasi*, *S. riobravis*, *S. feltiae*, *S. carpocapsae* and *H. bacteriophora*) (Abbas *et al*. 2001a; El-Bishry *et al*. 2000; Saleh and Alheji 2003).

The negative and poor results of nematode injection may due to the effect of the fermentation of RPW frass and palm damaged tissues by microorganisms resulting in alcohols and other toxic materials (El-Bishry *et al*. 2000).

Spraying. Abbas *et al*. (2000) along with Hanounik *et al*. (2000) sprayed palm trunks with a quantity of nematode suspension (2×10^6 IJs per tree) and (3.75×10^6 IJs per tree) respectively, enough to wet the trunk. While Abbas *et al*. (2000) released RPW individuals after palm treatment, Hanounik *et al*. (2000) released them before. The experiment of Hanounik *et al*. (2000) showed higher mortality rate.

Soil treatment. Abbas (2010) mentioned that soil around palm tress can be treated with nematodes.

17. 5 OTHER BIOLOGICAL CONTROL AGENTS

The infection of virus and its effectiveness was not approved clinically (Salama *et al*. 2004).

Yeast was isolated from RPW haemolymph (Danger 1997), and associated with RPW (Abe *et al*. 2010) it kills 50 % larvae of RPW in four days (Danger 1997).

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IMPORTANT

See Table (18 a, b, c) for information on the isolated natural enemies of RPW.

18 MALE STERILIZATION

18.1 STERILE INSECT TECHNIQUE (SIT)

SIT is a pest control method that reduces the pest population by area-wide periodically releasing of radiated sterilized male insects in the field, and then the released sterilized males mate with wild females from the same species (Baumhover 1966; FAO 2005; Hendrichs and Robinson 2009; Knipling 1968; Lindquist 2000; Morrison 2013).

SIT can be used when RPW population is low, while in case of high population other methods should be used first to reduce RPW population (Krishnakumar and Maheswari 2007).

The SIT program influenced by:

1) the dose of radiation (Al-Ayedh and Rasool 2010),
2) the insect age (linear relationship) (Ouye *et al*. 1964),
3) the longevity of sterilized male relative to wild female in the field (Al-Ayedh and Rasool 2010), the longevity affected by host plant cultivar (Al-Ayedh and Rasool 2010),
4) the mass rearing (when female reared with treated and non treated males the egg viability increase) (Krishnakumar and Maheswari 2004; Rahalkar *et al*. 1977),
5) the genetic factors (Meats 1998),
6) the sterilization and release procedures (Meats 1998) and
7) the ratio of sterilized males to normal females (10 to one respectively is needed for effective control of the pest population) (Al-Ayedh and Rasool 2010).

Moreover, the success of SIT is limited by the concealed nature of RPW and the opportunity for females to mate with normal males in the field (Faleiro 2006a).

The irradiation affected sperm quality (Liacer *et al*. 2013; Williamson *et al*. 1985), induced dominant mutation in the spermatozoids (Williamson *et al*. 1985), arrested the embryonic development (VanderVloedt *et al*. 1978), affects different biological parameters (Al-Ayedh and Rasool 2010; A.-Fetouh 2011; El-Naggar 2010; LIacer *et al*. 2013) and morphological parameters (El-Naggar 2010; Mahmoud *et al*. 2012).

18.1.1 GAMMA RAYS

Different authors suggested the use of 15 Gray (Gy) gamma rays in IPM program (Al-Ayedh and Rasool 2010; El-Naggar 2010; Krishnakumar and Maheshwari 2007; Liacer *et al*. 2013; Mahmoud *et al*. 2012).

Doses. Different doses of gamma rays such as 15, 16, 17, 18 and 20 Gray (Gy) (Krishnakumar and Maheshwari 2004), 10, 15, 20, 25 & 30 Gy (Al-Ayedh 2010; Al-Ayedh and Rasool 2010), 10 and 20 Gy (A.-Fetouh 2011) and 15 Gy (El-Naggar 2010; Krishnakumar and Maheshwari 2007; Liacer *et al*. 2013) were tested on RPW.

Affected generation. Ramachandram (1991) observed that gamma radiation had no effect on F2 generation. On the other hand, A.-Fetouh (2011) did not observe any significant difference in biological parameters such as egg incubation, larval, pupal and total life cycle periods of F3 progeny (resulted from the cross between treated males and normal females and treated females and normal males).

Effect of gamma rays on RPW biological parameters

Life span. A.-Fetouh (2011) reported that the doses of 10 and 20 Gy of gamma radiation caused significant prolongation to different RPW biological parameters such as egg incubation, larval, pupal and total life cycle periods for the F1 and F2 progeny (resulted from the cross between treated males and normal females and treated females and normal males), with six to seven days difference in total life cycle. She observed that this prolongation was significant in the progeny resulted from the cross between irradiated males and normal females than those resulted from the cross between irradiated females and normal males.

Egg incubation period was significantly longer only in F1 progeny of 20 Gy treatment males than the progeny of the 10 Gy irradiated males and the untreated weevils.

Male life span. Al-Ayedh and Rasool (2010) observed that the male life span reduced gradually with the increase of gamma radiation dose (at a dose ≥ 10 Gy).

Al-Ayedh and Rasool (2010) and Krishnakumar and Maheshwari (2004) revealed that a dose of 15 Gy of gamma rays was optimum for reducing male life span.

Al-Ayedh and Rasool (2010) and Krishnakumar and Maheshwari (2007) observed that the male could live 100 days after release.

Larval life span. A.-Fetouh (2011) observed that the larval period was significantly longer in the F1 and F2 progeny of both 10 and 20 Gy irradiated males than the progeny of the untreated weevils.

Pupal life span. A.-Fetouh (2011) observed that the pupal period was significantly longer only in F1 progeny of both 20 Gy treatment males than the progeny of the untreated weevils.

Effect of gamma radiation on the eggs of treated parents

Egg incubation period. A.-Fetouh (2011) reported that Egg incubation period was significantly longer only in F1 progeny of 20 Gy treatment males than the progeny of the 10 Gy irradiated males and the untreated weevils.

Egg hatchability. Al-Ayedh and Rasool (2010), El-Naggar (2010) and Liacer *et al*. (2013) revealed that a dose of 15 Gy of gamma rays was optimum in reducing egg hatchability.

Al-Ayedh and Rasool (2010) observed that egg hatchability reduced gradually with the increase of gamma radiation dose (at a dose ≥ 15 Gy). This decrease in egg hatchability might be due to the decrease of the quantity and quality of viable sperms (Al-Ayedh and Rasool 2010).

Egg viability. Krishnakumar and Maheshwari (2004) reported that eggs were more viable (65.9 %) when females were trapped without males than when they were trapped with males (58.9 %). When sterilized males replaced by normal ones the egg viability increased from 7 % to 67 %. This observed high viability of eggs laid by RPW females that were mated with sterilized males might due to sperm radio-resistance (Rahalkar and his colleagues 1973, 1975), or might be related to the fact that the females had already mated with normal males in the laboratory (Krishnakumar and Maheshwari 2004) or inside the infested palms before flying out for egg laying (Faleiro 2006a).

Effect of gamma rays on RPW morphological parameters

El-Naggar (2010) reported that the size and shape of the ovaries of the resulted progeny were affected by the sterilization of their parents. These effects include the damage of the oocyte maturation: elongation of the terminal filament,

separation of external sheath and follicular epithelium and absence of nurse cells, appearance of vacuolation inside the oocytes in some areas, the follicular epithelium was thinner than the normal case, oocytes clumped together throughout the ovariole resulted in an abnormal or rectangular oocytes shape.

Mahmoud *et al*. (2012) reported that the doses of 15 and 20 Gy of gamma rays affected the antennal sensilla coelocolica I, II & III, the sensilla chaetica I & II and the sensilla basiconica I. They also observed that 20 Gy gamma ray affected more number of sensillae, accordingly, theses authors suggested the rejection of the dose 20 Gy as it might had an affect on RPW behavior.

18.1.2 X-RAYS

The exposure of 1-2 day old RPW males to a dose of 1.5 krad of X-rays for 24 to 48 h (Hussain *et al*. 2013) induced 90 % sterility with no adverse effect on the length of adult life, higher doses induced complete sterility but shortened life (Rahalkar *et al*. 1973, 1975).

Rahalkar *et al*. (1973) observed that the male life span and egg hatchability were gradually reduced with the increase of X-rays dose (1, 1.5, 1.75, 2, 2.5 and 3 krad).

18.2 RIDL

RIDL is an alternative method to SIT that overcomes SIT shortcomings; its utility against RPW is under discussion (Alphey 2013; Morrison 2013). RIDL is a species specific and it is effective in the presence of low number of insects (Alphey 2013; Morrison 2013), RIDL strains cannot establish themselves in the field as they are inherently self-limiting so it is controllable and reversible and it was used successfully against other insect pests (Alphey 2013; Morrison 2013).

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19 CHEMICAL CONTROL

19.1 SMELL (OLFACTION)-REMOTE DETECTION-CHEMICAL SIGNATURES OF INFESTATION

Infested palms emit characteristic volatiles; the naked nose of trained dogs can detect theses volatiles (Lewis and Tumlinson 1988; Nakash et al. 2000). Golden Retriever (GR) and Rottweilers (RW) can recognize those volatiles (Lewis and Tumlinson 1988; Nakash *et al*. 2000; Turling *et al.*1990) with more than 70 % accuracy (Nakash *et al*. 2000).

This procedure is effective and inexpensive for early detection of infested palms at small-scale areas as well as quarantine (Soroker *et al*. 2013). However, the climate conditions affect the work hours of the dogs (Soroker *et al*. 2013).

Different parameters need further researches, these parameters include:

1) the species specific of emitted volatiles (Soroker *et al*. 2013, 2014),
2) the components of these volatiles (Soroker *et al*. 2013, 2014),
3) the effective range of dog sensitivity (Soroker *et al*. 2013, 2014),
4) the ability of dogs to detect the infested palm in case of crown infestation (Soroker *et al*. 2013, 2014),
5) the automation of the procedure by using olfactory sensors (electronic nose or tongue) (Soroker *et al*. 2013, 2014), and
6) the application of the procedure at large area scale is needed further researches (Soroker *et al*. 2013, 2014).

19.2 MASS TRAPPING

Semiochemicals produced by RPW (pheromones) and/or by preferred host plants (kairomones) can be used to mass trapping RPW. Mass trapping RPW can serve as an early detection, preventive and/or curative method (Faleiro *et al*. 1998; Soroker *et al*. 2005). It was successful only when combined with good sanitation and chemical control. It allowed to reduce the weevil population and to reduce the number of flying adults (Abbas 2013).

19.2.1 TYPES OF SEMIOCHEMICAL-BASED TRAPS

There are four types of semiochemical-based traps:

1) Kairomone traps. Natural extracts from preferred plants could be used alone or in combination with pheromone in mass trapping RPW (Dickens 1989). Different natural (food baits) and synthetic (extracts) attractants for RPW were used successfully in bait traps of RPW (Table 19).

Types and chemical composition of kairomones. RPW was attracted by several kairomones. Coconut sap consists mainly of short chain alcohols (C-2-5) (Samarajeeva and Adams 1983). RPW was more sensitive to Ethyl propionate and ethyl acetate than esters, ethyl butyrate, ethyl isobutyrate, ethyl lacta (Guarino *et al*. 2011).

Components such as γ-nonanoic lactone and 4-hydroxy-3-methoxystyrene possess electrophysiological activity (EAG) (Gunawardena *et al*. 1998).

Kairomone source quantity. The quantity of 100 g of date palm in the trap was sufficient in RPW trapping; no significant catch was detected using more (Abuagla and Al-Deeb 2012).

Al-Saoud (2013) and Al-Saoud and Ajlan (2013) found that 450 g was better than 350 and 550 g in the number of trapped weevil.

Time. Adult of RPW responded towards attractants during the first two weeks after emergence, males responded faster than females (Gunawardena and Gunatilake 1993).

Palm age. Although RPW antenna did not show any significant difference in the response to the young and old *C. nucifera* bark steam distillates (Gunawardena and Swarnakanthi 1995), trapped RPW were higher on young coconut palms than on older palms (Gunawardena *et al*. 1998). This observation may due to the fewer injuries on the hardened barks (Gunawardena and Swarnakanthi 1995).

Distance of attraction. Ethyl and isopropyl alcohols played an attractive role at short distances, while Chirality and the presence of specific olefinic bonds are responsible for longer distances (Gunawardena and Gunatilak 1993).

Short chain alcohols were more effective in attracting the walking weevils from a short distance (Gunawardena and Gunatilak 1993; Gunawardena and Herath 1995) compared to ferrugineol that was effective in its luring from a distance (Gunawardena and Herath 1995).

Attracted sex. RPW males responded to semiochemicals faster than females, both sexes can be attracted during the first two weeks after emergence (Gunawardena and Gunatilake 1993).

Female antennae were more sensitive to esters than male antenna (Guarino *et al*. 2011).

Electroantennogram (EAG) responses of adult male and female RPW to the total steam distillate of the volatiles of the young coconut bark (ethanone-1 (2-hydroxy-5-methyl), 4-hydroxy-3 methoxybenzaldhyde, acetophenone, phenol, xylene, nonanol, decenal, diethylene glycol, nonanoic acid and α-ionone) were significantly great (32.3±6.9) (Gunawardena 1994).

Both RPW sexes were attracted greatly by pentanol in comparison to ethyl, n-butyl or n-propyl (Gunawardena and Kern 1994), n-propanol, n-nonanol, n-hexanol (Gunawardena and Herath 1995).

Chemoreceptive sensitivity. The chemoreceptive sensitivity of RPW based on: 1) the size and the position of the oxygen function, 2) the degree of unsaturation (favor high unsaturation or cyclic low unsaturated terpenes structures with nonterminal –OH/C = O functionality in the molecule), and 3) the arrangement of olefinic bonds in the terpenes molecules (Gunawardena 1994).

2) Pheromone traps. RPW aggregation pheromone is used to mass trapping RPW (Abraham *et al*. 1998; Abraham *et al*. 2001; Al-Saoud 2004; Al-Saoud and Ajlan 2013; Al-Saoud *et al*. 2010; Faleiro 2006a; Faleiro and Rangnekar 2001; Faleiro *et al*. 1998, 2011; Fiaboe *et al*. 2011; Gunawardena and Herath 1995; Hallett *et al*. 1999).

Although pheromone traps could reduce RPW density and could be a protective procedure, they are not 100 % efficient (Ferry and Gomez 2012). Their effectiveness was influenced by many factors, including color (Abdalah and Al-Khatri 2005; Ajlan and Abdulsalam 2000; Al-Saoud *et al*. 2010; Hallett *et al*. 1999) pheromone type (Faleiro and Chellapan 1999; Faleiro and Satarkar 2003), trap contents (Al-Saoud 2007; Al-Saoud 2009), food bait (Al-Saoud 2011a; Faleiro 2004; Nair *et al*. 2000), and trap location (Al-Saoud 2011b; Faleiro 2004; Hallett *et al* 1999; The Alameda 2008). The utility of pheromone traps was determined by the pest density where they were more sufficient when the infection was low, they were recommended only when the pest appear in the area (The Alameda 2008).

RPW pheromone. The Aggregation pheromones attract both RPW sexes so they are more suitable than sex pheromones in mass trapping (Gunawardena and Bandarage 1995).

Although the male aggregation pheromone Ferrolure was not extracted from RPW (Rugman-Jones *et al*. 2013); it played a principal role in attracting RPW (Carde 1984; Rugman-Jones *et al*. 2013; Weissling *et al*. 1994; among others). This may due to common compound in the different *Rhynchphorus* spp. pheromones that had a role in attracting the different species (Rugman-Jones *et al*. 2013).

Rugman-Jones *et al*. (2013) suggested extracting, identifying, and testing RPW pheromone.

The used aggregation pheromone (produced by male) was a mixture of 4-methyl-5 nonanol (ferrugineol) and a major component 4-methyl-5 nonanone (ferrugineone) (Hallett *et al*. 1993).

Comparison among different pheromone lures. The efficacy of Tripheron+ (available as granules, 200 mg + synergist) and Ferrolure+ (available as liquid, 700mg + synergist) was higher than Tripheron (1000 mg) and Ferrolure (available as liquid, 400 mg) in both attracting RPW and in their persistence period in field (Krishnakumar and Maheswari 2004).

Pherobank lure (400 mg) from Holland was superior than Ferrugineol based lures from Costa Rica and USA (Faleiro 2005). CPRCI lure was 50 % efficient in attracting RPW as compared to Ferrolure +800 mg (Faleiro 2005).

Abbas and Al-Nasser (2012) compared among three different commercial pheromones from Costa Rica (Chemtica company), France (Qaluibe company) and Spain (Sedq Espana). These pheromones consists of 4-methyl 1-5-nonanol (9 parts), 4-methyl nonanone (1 part), (99.9 % purity), 0.1 % colorant and 0.1 % antioxidant. The Costa Rica type pheromone was more attractive than the France and Spain type pheromone.

Rate of lure release. A uniform release of the pheromone was important (Abdallah and Al-Khatri 2005; Faleiro *et al*. 1998; Poorjavad *et al*. 2009; Zada *et al*. 2002). High release lure was more efficient in RPW capture compared to low release (Faleiro *et al*. 2000). A release rate of 0.48 mg/day (Faleiro 2005), 3 mg/24 h (Hallett *et al*. 1999). Lure stayed active for six months in shad (Faleiro 2005).

A linear release rate was observed at the first 58 days (8 mg/day/ at 23.5-36.6 °C), this rate declined 50 % for another 40 days/ at 17-29.8 °C, in addition it declined more rapidly in summer (27-37 °C) than winter (13-23 °C) (Abdel Moety *et al*. 2012). This difference in seasonal decline should be put in consideration when semiochemical traps are applied in hot regions (Abdel-Moety *et al*. 2012).

3) Pheromone / kairomone traps. A combination of both pheromone and Kairomone (either volatiles or food baits) were used in these traps. This combination had a positive synergistic effect on the catch (Abdallah and Al-Khatri 2005; Abozuhairah *et al*. 1996; El-Sebay 2003; Faleiro and Chellapan 1999; Faleiro and Rangnekar 2001; Faleiro and Satarkar 2002; Guarino *et al*. 2011; Gunawardena and Bandarage 1995; Gunawardena and Herath 1995; Hagley 1965; Hallett *et al*. 1993, 1999; Oehlschlager *et al*. 1993; Vidyasagar *et al*. 2000).

The pheromone-alcohol baited trap was potentially useful for RPW trapping; this might due to the mix simplicity, the long lifetime of the bait, the uniformity of release rate and the high trap catch (Gunawardena and Herath 1995).

A mixture of ferrugineol with n-pentanol was more synergistic than the mixture of ferrugineol and n-hexanol (Gunawardena and Herath 1995).

4) Pheromone/mineral oil trap. Conti *et al*. (2013) reported that a combination of mineral oil with pheromone was used successfully in mass trapping RPW.

19.2.2 TRAP DESIGN

Different traps were tested in different experiments. The capture differences of these traps depended on their design (Rajapakse *et al*. 1998).

Kurian *et al*. (1979) proved the superiority of coconut logs over metal traps. The metal trap had limitations due to its high cost, the short intervals for servicing and its low capture. In addition, in the metal as well as the funnel trap the bait was suspended inside the funnel and the inner metal tray respectively, this suspension interrupted the dispersion of the pheromone making it less attractive (Rajapakse *et al*. 1998).

The open bucket trap was the most appropriate trap design to be baited with pheromone (Rajapakse *et al*. 1998). In the open plastic bucket, the bait was suspended on the rim of the bucket, and it was fully exposed to the environment, therefore the pheromone odor from the bait could be carried out by the wind (Rajapakse *et al*. 1998).

Reusable beetle trap and reusable bucket trap showed the highest mean number of captured adults compared to reusable Saudi bucket trap opened from side and the reusable Saudi bucket trap opened from top (Ajlan and Abdulsalam 2000).

The five liters plastic bucket trap has four windows (5 X 1.5 cm) cut equidistantly just below the upper rim of the bucket, a jute sack cloth was stuck on the exterior surface of the bucket to provide better grip for the attracted RPW, enabling them to crawl into the trap (Faleiro 2005; Faleiro *et al*. 1998). The pheromone lure was hanged on the under side of the bucket lid (Faleiro *et al*. 1998). Conti *et al*. (2013) used a 15 liters trap designed as above.

19.2.3 TRAP COLOR

Faleiro (2005) concluded that trap color had not affected RPW catch. However, other authors noticed that RPW was not attracted equally to different trap colors accordingly; Hallett *et al*. (1999) concluded that vision might be important in RPW host selection.

Trap colors such as Red (Al-Saoud *et al*. 2010), Green (Ajlan and Abdulsalam 2000) and brown-reddish (Sansano *et al*. 2008) attracted more RPW compared to White and Yellow ones.

Red color traps attracted more RPW followed by Green (20.6 %), Orange (19.7 %), Yellow (18.1%) and bleu (14.7 %) (Al-Khatri *et al*. 2009).
Female were attracted more than males by Red, Green and Bleu (Al-Khatri *et al*. 2009), red, orange and bleu (Abd-Allah and Al-Khatri 2005).
Reusable beetle trap (yellow/green) and reusable bucket trap (green) showed the highest mean number of captured adults compared to reusable bucket trap (white/yellow/green) (Ajlan and Abdulsalam 2000).
Black traps were significantly high compared to red, yellow (Abuagla and Al-Deeb 2012) and white traps (Abuagla and Al-Deeb 2012; Hallett *et al*. 1999).
Black trap was more attractive to RPW, so it might be used in summer more than in other months. The high potential of black trap over red one might due to either its high temperature that result in high release of pheromone or its color similarity as the palm trunk color (Conti *et al*. 2013).
RPW responded to vane traps with black-painted vanes more than those with reflective unpainted vanes, this may resulted from the higher pheromone release rated from black traps due to heating of the vanes (Hallett *et al*. 1999).

19.2.4 TRAP PLACEMENT

Young or old palm. It was recommended to hang traps on old not young palms (Faleiro *et al*. 1998; MOEW 2014).
Height. When traps placed at the ground level, they gave more efficient results than when hanged on the palm (Conti *et al*. 2013; Faleiro 2005; Hallett *et al*. 1999). However, traps were hanged on palms at 1 to 1.5 m above the ground level, for practical reasons (Faleiro 2005; Faleiro *et al*. 1998).
The efficacy of trapping RPW decreased when traps were placed at a height of more than 2 m, while no RPW was trapped at 10 m. In contrast, Hallett *et al*. (1999) mentioned that trap capture was higher by placing traps at 2 m high.
Sun or shadow. When traps exposed to direct sun light, the pheromone exhausted faster as compared to traps set under the shade (Faleiro *et al*. 1998). In addition, traps settled in shade retained water longer (Faleiro 2005).

19.2.5 TRAP DENSITIES

The agroecosystem involved and the resources available would influence the decision on trap density to be used (Faleiro 2006b) (Table 20).

19.2.6 RETAINING OF TRAPPED INSECTS

An additive insecticide solution can be used to kill and retain captured weevils (Ajlan and Abdulsalam 2000; Faleiro *et al*. 1998; Hallett *et al*. 1999; Lambe 2008). However, free pesticide funnel traps were effective in retaining captured weevils (Hallett *et al*. 1999; Rajapakse *et al*. 1998). In addition, the trapped weevils were retained successfully when drowned in water (Fiaboe *et al*. 2011; Lambe 2008; Rajapakse *et al*. 1998) or soap solutions in the bottom of the trap (Lambe 2008; Rajapakse *et al*. 1998).

19.2.7 TRAP SERVICING

Traps should not be left dry as RPW could move on the smooth surface and climbed to the top of the dry trap in few seconds to less than 5 min then escape outside (Fiaboe *et al*. 2011).

The evaporation rate should be prevented in the future to prevent RPW escape from the trap to improve its efficacy (Fiaboe *et al*. 2011).

Replacement of kairomone. The age of the food bait and semiochemicals mixture is an important factor affecting trap catch (Fiaboe *et al*. 2011).

During the winter, the trap kairomone lasted for two weeks, whereas in the summer it decomposed faster and had to be replaced every week (Faleiro *et al*. 1998, 2011; Fiaboe *et al*. 2011).

The trap kairomone should be replaced once a week, under the Middle East conditions (Faleiro *et al*. 1998, 2011; Fiaboe *et al*. 2011).

The best weevil captures were obtained when: food bait was replaced every ten days (Faleiro 2006b), when molas was replaced each 7-8 days (Faleiro *et al*. 2011).

Lures Handling and Storage. Pheromone lures can be degraded by elevated heat and direct sunshine, also, its cross contamination can lead to mixed catches or reduction in RPW catches by repellent contaminants. The lure shelf life varies from 3-36 months depending on the storage temperature (must be stored in cold temperature) (Russell IPM 2013). It was recommended to replace the pheromone each two months (Conti *et al*. 2013).

Insecticide. The trap insecticide solution should be replaced once a week, under the Middle East conditions (Faleiro *et al*. 1998, 2011; Fiaboe *et al*. 2011).

The best weevil captures were obtained when insecticide solution was replaced every ten days (Faleiro 2006b).

19.2.8 RPW BEHAVIOR AROUND AND IN THE TRAP

The weevils approaching traps gradually, they flew 1.5-2 m above the ground until they land on or near the traps (Rajapakse *et al*. 1998). They moved from seconds to less than five minutes on the inner surface of the bucket, then they dropped in the presence of water, where they could swim but could not climb the wall. They could stay alive for two weeks in water (Conti *et al*. 2013).

19.2.9 ATTRACTED WEEVILS AND SEX PERCENTAGE

Weevils were captured 3 to 5 days post release (UAEIR 2006). Although both males and females were attracted to pheromone traps, the captures were reported to be female dominated (Abdallah and Al-Khatri 2005; Abraham *et al*. 1999; Al-Saoud and Ajlan 2013; Ajlan and Abdulsalam 2000; Faleiro 2005; Faleiro and Chellapan 1999; Faleiro and Satarkar 2003b; Faleiro *et al*. 2000; Rao and Sujatha 2004; Oehlschlager 1994; Rao and Sujatha 2004) (Table 21).

This was contrary to the reports by Abbas *et al*. (2006), Hallett *et al*. (1993) and UAEIR (2006) who found no significant differences in rates of capture between males and females.

Mostly females were attracted and trapped by pheromone traps in date plantations (Abraham *et al*. 2001). This can play a significant role in suppressing the RPW populations in the field (Abraham *et al*. 2001; Faleiro 2000; Faleiro and Chellapan 1999; Vidyasagar *et al*. 2000).

19.2.10 LOCATING THE SOURCE OF INFESTATION

Once the number of trapped RPW was calculated, the source of infestation from where the insect is released can be then identified (Faleiro *et al*. 1998). In this regard, farms located in a radius of 100m around a particular trap were examined (Faleiro *et al*. 1998).

It was often difficult to locate the source of infestation when the trap density was very low and wide stretches of gardens were served by a single trap (Faleiro *et al*. 1998).

Faleiro *et al*. (1998) recommended setting three to four additional traps as indicators, 200 to 300m around a particular trap.

19.2.11 ADVANTAGES OF MASS TRAPPING

Semiochemical based traps are environmental friend tools (Abuagla and Al-Deeb 2012; Al-Saoud and Ajlan 2013; Faleiro *et al*. 1998), practical, easy and simple (Faleiro 2006b). In addition, the most trapped RPW were females (Abraham *et al*. 2001; Faleiro 2000; Faleiro and Chellapan 1999; Vidyasagar *et al*. 2000).

19.2.12 DISADVANTAGES OF MASS TRAPPING

The use of food baits and natural plant parts as attractants had various disadvantageous such as: 1) the need to weekly replacement; 2) their attractiveness varies considerably with environmental conditions as a maximal trap catch was observed on the fifth day then declined thereafter (Gunawardena and Herath 1995; Hallett *et al*. 1999).

Those disadvantages can be countered by trapping servicing periodically, all palms surrounding a trap (50-100 m radius) may be periodically secured with insecticide cover sprays (Faleiro 2006b).

19.3 ANTI-FEEDING AND REPELLANT CONTROL

Abdullah (2009a) reported that the rotenone and limonene were effective as antifeeding for RPW larvae and lethal for both larvae and adults at high doses.

Shukla and his colleagues (2012) revealed a significant antifeedant activity of three EOs extracted from two plants of Asteraceae family, crofton weed, *Eupatorium adenophorum* (Spreng.) (flowers (EEOF) and leaves (EEOL)) and Indian wormwood, *Artemisia nilagirica* (C.B. Clarke) (Pamp.)(aerial parts (AEOL)) against RPW adults. The three antifeedant composed of diterpenes, monoterpene hydrocarbons, oxygenated monoterpenes, oxygenated sesquiterpenes, sesquiterpene hydrocarbons and others with different percentages.

The EEOF and AEOL showed a significant antifeedant activity against RPW. Where they caused 53.35 & 52.86 % and 60 % reduction in feeding after 72h & 96 h and 24h qt 1000 ppm respectively (Shukla *et al*. 2012).

Their effectiveness differences may due to their different chemical composition, where EEOF is biased towards sesquiterpene hydrocarbons and their oxygenated derivatives, while both monoterpene and sesquiterpene hydrocarbons is more than their oxygenated derivatives in AEOL (Shukla *et al*. 2012).

The antifeedant activity of AEOL reduced gradually over the time, this may due to the high volatility of the camphor. On the other hand, the EEOLO was not effective as antifeedant (Shukla *et al*. 2012).

The Eos extracted from different plants or from same plant but different parts of the same plant differs in their biological activity as a result of their chemical composition differences (Shukla *et al*. 2012).
Al-Shawaf *et al*. (2013) reported that treating the palm wounds with 1 % azadirachtin deter RPW oviposition.

19.4 DIGESTIVE ENZYMES INHIBITION

Digestive enzymes inhibitors may be used to affect negatively the larval development, this goal can be achieved by using non-preferred feeding materials, adding the inhibitors to the feeding material, or integrating a gene carrying the inhibition in tissue culture (Alarcon *et al*. 2002).

19.5 INSECT GROWTH REGULATORS (IGRS)

IGRs such as enzymes and hormones that regulate developmental process can be used either to stimulate or inhibit development at appropriate times (Meyer 2003).
IGRs were recommended all the year on the infected palms (The Alameda 2008).
Three doses of two IGRs were used effectively against RPW prepupa (El-Bokl *et al*. 2010).
Natural IGR. Azadirachtin: a liminoid component of the neem seed extract (*Azadirachta indica*, Meliaceae) (Schroeder and Nakanishi 1987), three doses: 50, 100, 500 ppm (El-Bokl *et al*. 2010).
Synthetic IGR. Flufenoxuron: a chitin synthesis inhibitor, C21H11ClF6N2O3, IUPAC name: 1-[4-(2-chloro-α,α,α-trifluoro-*p*tolyloxy)-2-fluorophenyl]-3-(2,6-difluorobenzoyl) urea (Mitsui 1985), three doses: 0.05, 0.1, 0.5 ppm (El-Bokl *et al*. 2010).
IGR effects
Lethal, morphological and biological effects. The lethal effect of both previously mentioned IGRs was more obvious on the pupal stage, it was positively related to the dose (El-Bokl *et al*. 2010). They were capable of: reducing the number of the emerged weevils, reducing the maximal body size (length & width) with no differences between males and females, causing morphological abnormalities to the emerged adults, affects the pupational duration where it was reversely related to the dose and Causing mortality percentage in males more than females as emerged females are more than males with no effect of the dose differences in case of Flufenoxuron (El-Bokl *et al*. 2010).
Histopathological effects on the gonadal
Ovary. IGRs disrupt female gamete production and due to a decrease in female fecundity and egg viability through the retardation of the ovarian development such as the increases in oocytes resorption, the delay of follicle development, the destruction of follicular epithelium (degeneration, hyperplasia and necrosis of the follicular cells) and the delay of oocytes development (degenerative, abnormal distribution of yolk granules (vitellogenesis), cytoplasmic vacuolization) (El-Bokl *et al*. 2010).

Testis. Both IGRs disrupted male gamete production through the defects in testicular architectural such as reduction in testes and testicular follicles size, germ cells necrosis, displacement of testicular cysts, decrease of the number of cysts of the spermatocytes and spermatogonia, depopulation of germ cells and the decrease in the number of spermatozoa (El-Bokl *et al*. 2010).
The effects of the two IGRs on the testis were dose-dependent where neem extract had the higher effect. The lower concentrations of both IGRs had narrower follicles with reduction in the cellular content, while higher concentrations showed disorganization and decreasing of the cellular content (El-Bokl *et al*. 2010).

19.6 INSECTICIDES

Chemical control using pesticide is recommended in infected areas as a treatment and in the surrounded area as a preventive method (Ferry and Gomez 2012), where it is recommended all the year on the infected palms and from June to September as protective method (The Alameda 2008). Several chemical components were used as preventive and/or curative methods against RPW (Abraham *et al*. 1975; Abraham *et al*. 1998; Al-Shawaf *et al*. 2013b; Barranco *et al*. 1996; Bream *et al*. 2001; Cabello *et al*. 1997; El-Ezaby 1997; Ferry and Gomez 2012; Hallett *et al*. 1999; Kurian and Mathen 1971; Lakshmanan *et al*. 1972; Murthy and Amonkar 1974; Muthuraman 1984; Rao *et al*. 1973). Although pesticide application is fast and effective, El-Bokl *et al*. (2010) reviewed that the chemical control was undesirable due to its negative effect on the treated area environment (Abuzuhairah *et al.* 1996; Moura *et al.* 1995). In addition, a high volume of pesticide is required to be effective, as well it should be repeated each month (Abraham *et al*. 1998; Ferry and Gomez 2012; Hallett *et al*. 1999).

Regarding the pesticide I refer here to some of the previously used pesticides (Table 22) as a review for students and / or researchers, but for actual application, I recommend you to consult the official agriculture institute in your country to provide you with the last updated pesticide

Dusting. Azam *et al*. (2001) mentioned that in date palm, dusting the whole palm with insecticide had disadvantages.

Fumigation. In this method, a slow released fumigant tablet that penetrates the commodity is placed in holes on the trunk then the holes are sealed (Abraham *et al*. 1998; Muthuraman 1984; Rao *et al*. 1973). OJ (1991) reported that methyl bromide (CH3Br) was the most commonly used fumigant either for treatment or for quarantine but it was forbidden after March 2010 in EU as it is an ozone depleting substances. Liacer and Jacas (2010) referred to aluminium phosphide in palms as an efficient, safe and low cost quarantine treatment against RPW, it reduced significantly the risk of imported palms. . However several authors concluded that aluminum phosphide was not effective as a treatment method in RPW management due to the escape of gas through many tree crevices, and the difficulty for the gas to

diffuse due to the blocking of larval tunnels by their feces and frass (Abd-Allah and Al-Khatri 2000b; Abraham *et al*. 1998; Ferry and Gomez 2012; Hallett *et al*. 1999). Azam *et al*. (2001) found that the pupae required the highest dose to be killed

Lure and kill. Insecticide solution can be used in semiochemical traps to kill captured RPW (Ajlan and Abdulsalam 2000; Faleiro *et al*. 1998; Hallett *et al*. 1999; Lambe 2008). Mafra-Neto *et al*. (2013) found that using the bait free attract and kill technology could reduce the cost of area wide IPM program due to elimination of trap servicing and avoid the risk of bait lure synergy when used in healthy areas.

Painting. The semi- field trial of the paint insecticidal (based on Chlorpyrifos and Pyriproxyfen) in microencapsulated formulation showed potential as protective where one single application was enough for six months (Liacer *et al*. 2010). On the other hand the laboratory trial showed no potential effect against RPW (Liacer *et al*. 2010).

Trunk infusion (soaking, dipping). Palm stems are soaked with pesticide each two months to prevent egg laying (Abraham *et al*. 1998). Azam *et al*. (2001) reviewed that soaking of palms with insecticides with a special soaking lance was an effective preventive measure. The insecticide solution that runs of the trunk formed a thin film and reached cracks and crevices and cut surfaces, making these sites unsuitable for egg laying. Soaking also gives an additional curative benefit as percolation of the chemical can kill different RPW stages (Abraham *et al*. 1998). Al-Shawaf *et al*. (2013a) mentioned that dipping date palm offshoots in a suitable pesticide (0.004 % Fipronil for 30 min) before transporting (72 h) would ensure complete mortality of the hidden larval stages. Dipping of palms protect them against RPW for 11 to 13 weeks (El-Sebaey 2004b). Pesticide applications should be repeated to avoid an increase in RPW population density (Conti *et al*. 2008).

Spraying. Pesticide is targeted as spray or shower using a special spray lance (Abraham *et al*. 2001) to the internal base, and the lower parts of the fronds emerged from under the soil (Al Naeemy 2012; Ferry and Gomez 2012), to 50 cm high (Al Naeemy 2012). In this treated area the pesticide will act as a reservoir as it is protected from the sun so last longer (Ferry and Gomez 2012). This practice is effective, but should repeated each month (Ferry and Gomez 2012). In addition, its frequency, cost and difficulty make its application not practical at large scale (Ferry and Gomez 2012).

Injection. In this method, three holes of 12-15cm deep and 1.5cm diameter are digged into the infested palm region, one in the infested area and the other two 20m above and below the infested area, an insecticide (10ml) is poured then the holes are covered with cement (Abdallah and Al-Khatri 2000b; Azam *et al*. 2001; Gunawardena and Gunatilake 1993) or soil. This practice kills larvae that come into contact with the insecticide (Gunawardena and Gunatilake 1993). The injection

method was used successfully in Oman resulting in 100% mortality (Abdallah and Al-Khatri 2000b). Nirula (1956) recommended the administration of the insecticide into the affected part of the stem using a funnel. Abbas (2013) reported that the chemical pesticide was more effective than the biopesticide, he also mentioned that injection by a mixture of kerosene and insecticides were sufficient for control severely infected palms. He explained that the synergistic action of kerosene due to 1) its function as chemical carrier throughout the tissue fibers of the infested roots, 2) its dehydration function, where it caused fast dryness of the wood, as well the insect cuticle (El-Sebaey 2004a).

Endotherapy. The palm is injected systematically with an appropriate pesticide (Avermectnes) annually (Ferry and Gomez 2012). This method is simple, less expensive, and health and environmentally friendly (Ferry and Gomez 2012). Researcher tried another pesticide but it was less effective and need to be repeated each two months (Ferry and Gomez 2012).

Soil treatment. In this method, a hole around the palm is digged, throwing granules pesticide is thrown, the soil is then covered, and this practice is repeated each 2 to 3 months as required (Al-Bakry 2012). The imidacloprid-formulated compound gave excellent control, in the semi-field and field experiments, when applied with soil-drench-irrigation. The residues of imidacloprid were detected in all plant parts (Kaakeh 2006).

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IMPORTANT:

See section I-10 for more details on RPW symptoms of infestation.

Regarding the pesticide I refer here to some of the previously used pesticides as a review for students and/or researchers, but for actual application, I recommend you to consult the official agriculture institute in your country to provide you with the last updated pesticide.

See :

Table 19: Different kairomones approved to attract RPW.

Table 20: Different trapping densities.

Table 21: Sex percentage of attracted weevils.

Table (22a, b, c): Chemical products tested and/or used to kill RPW.

FIGURES

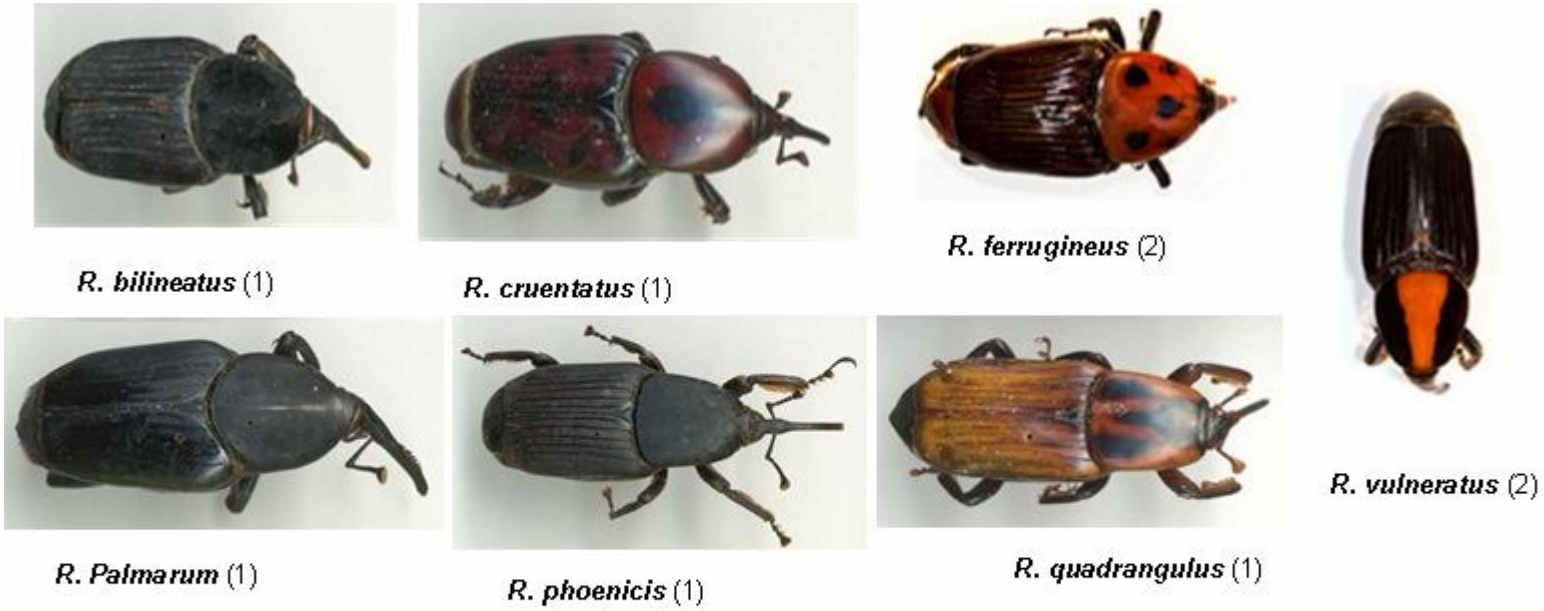

Figure (1): Adult stage of different *Rhynchophorus* spp. Images source: (1)Giblin-Davis (2010); (2) Rugman-Jones *et al*. (2013).

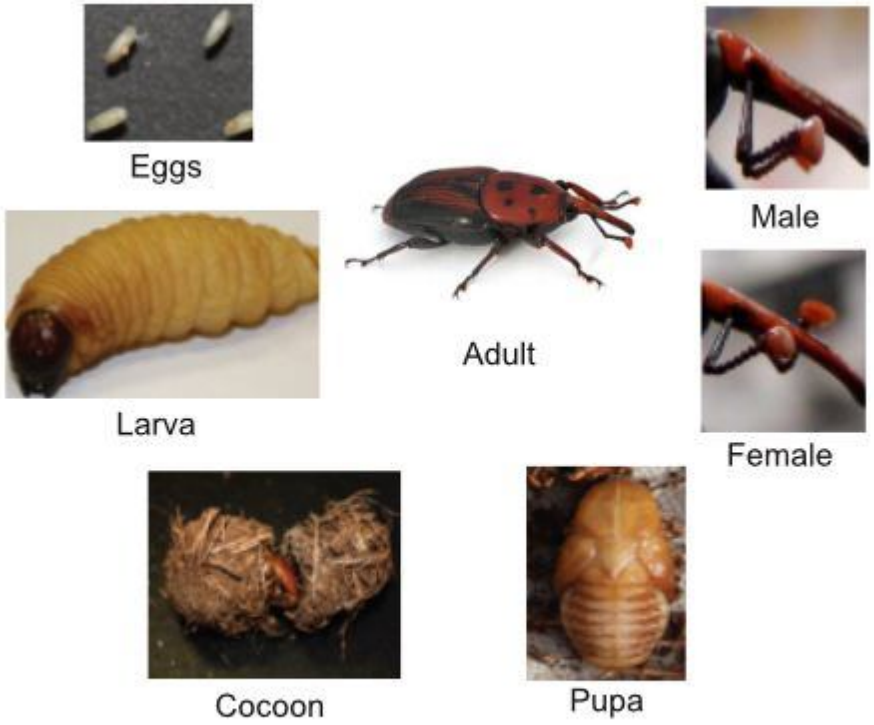

Figure (2): Different RPW stages.
source: Vidyasagar and Aldosary (2011).

Figure (3): Phylogenetic tree of *Cyt*b hapolotypes of RPW : the tree was reconstructed using: maximum parsimony (MP) method. Bootstrap support values (1000 replicates) are indicated above the lines (El-Mergawy 2011, 2012 , 2013).

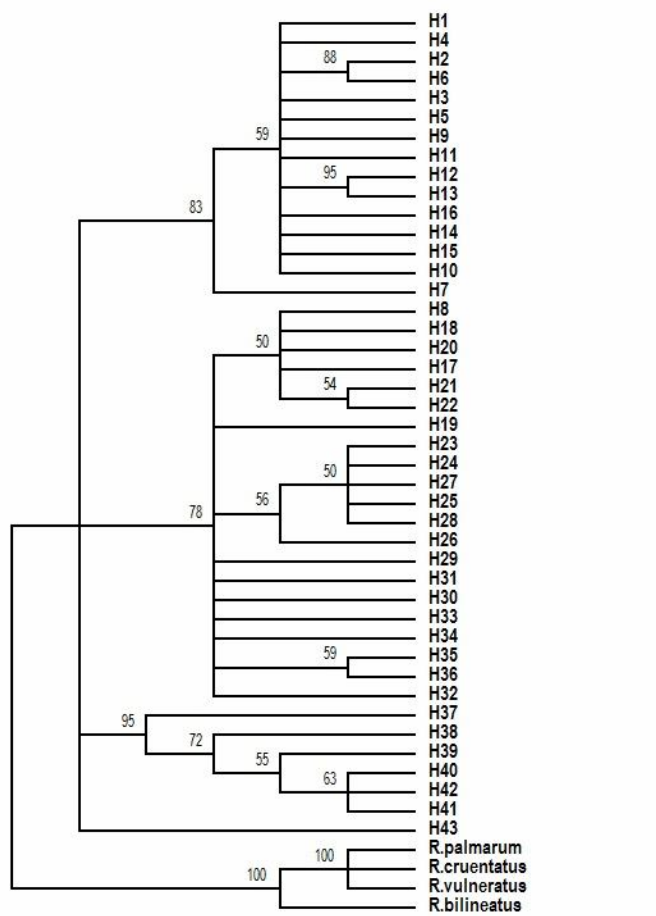

Figure (4): Phylogenetic tree of CO1 hapolotypes of RPW : the tree was reconstructed using: Neighbor Joining (NJ) method. Bootstrap support values (1000 replicates) are indicated above the lines (El-Mergawy,

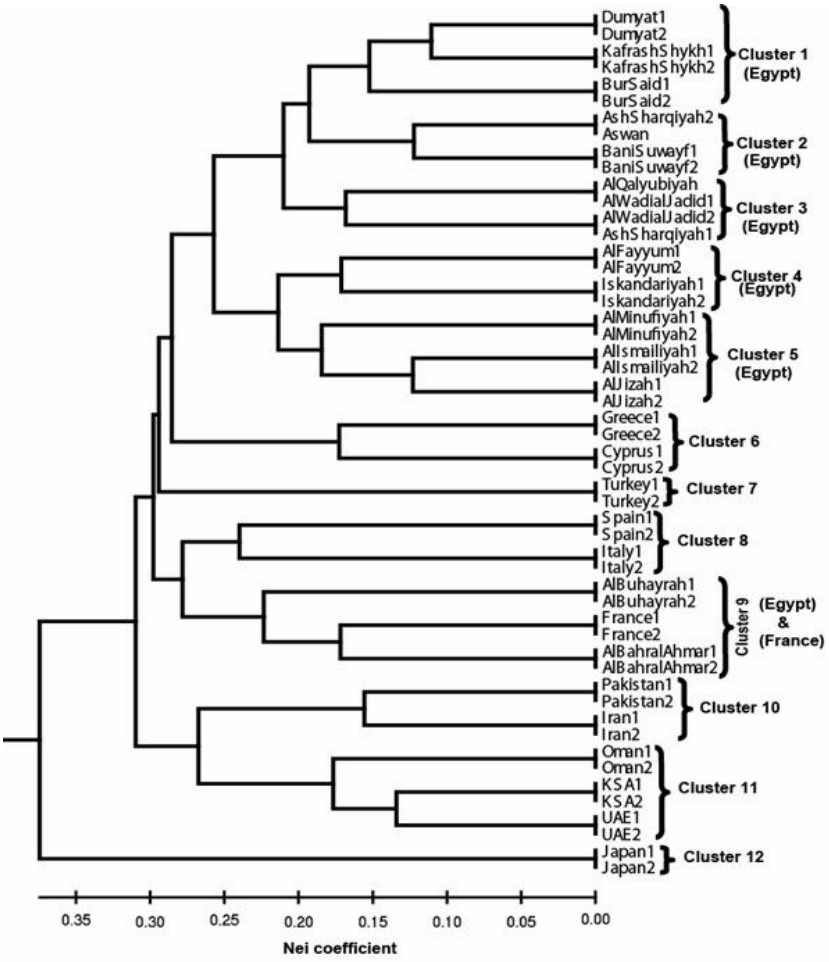

Figure (5): Cluster analyses of RPW-UPGMA dendrogram (El-Mergawy 2011, 2012, 2013).

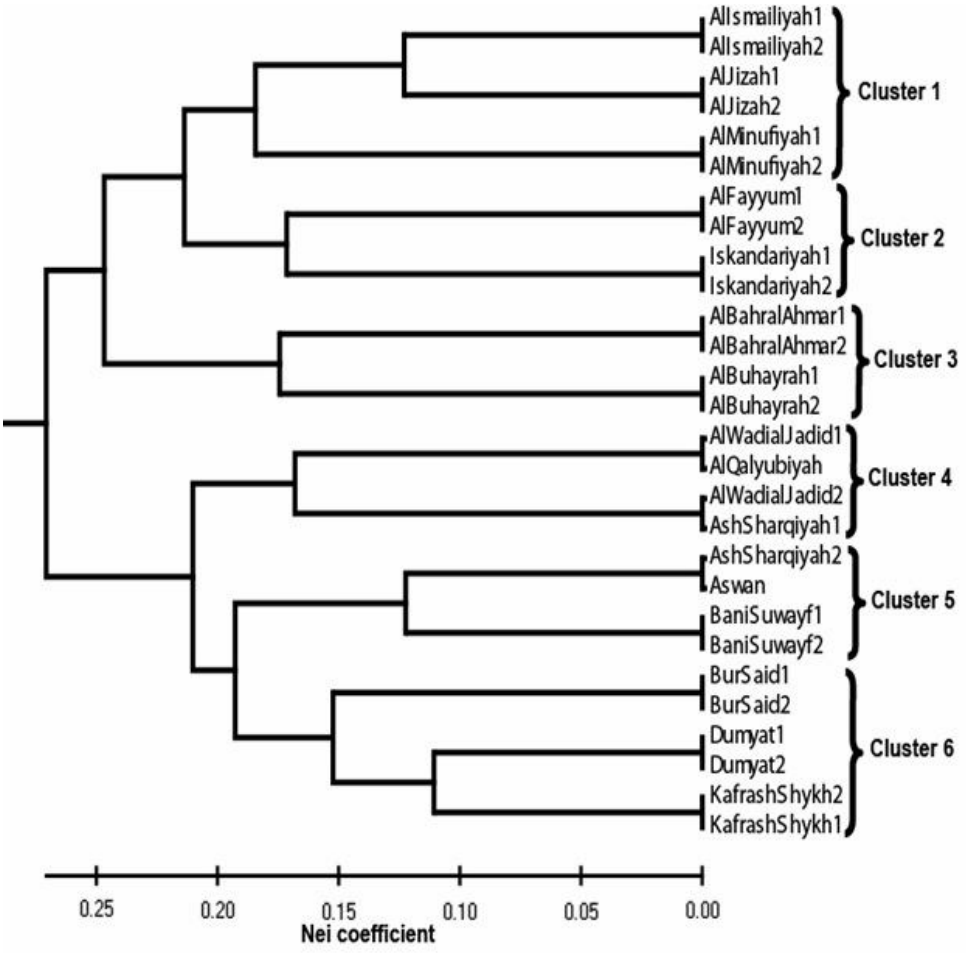

Figure (6): Cluster analyses of Egyptian RPW-UPGMA dendrogram (El-Mergawy 2011,2012, 2013).

Figure (7): Symptoms of RPW infestation: palms without neither offshoot nor wound at their base: A) large cavity at the top

Figure (8): Symptoms of RPW infestation: A) medium level of RPW infestation (II) at the bole area, B) severe level (III) of RPW infestation (Vidyasagar and Aldosary 2011).

Figure (9): Symptoms of RPW infestation: a) medium (II) level of RPW infestation: young palm after removing damaged tissues, b) severe level (III) of RPW infestation: A) chewed up fibers, B) RPW adult near the bored hole on the stem (Vidyasagar and Aldosary 2011).

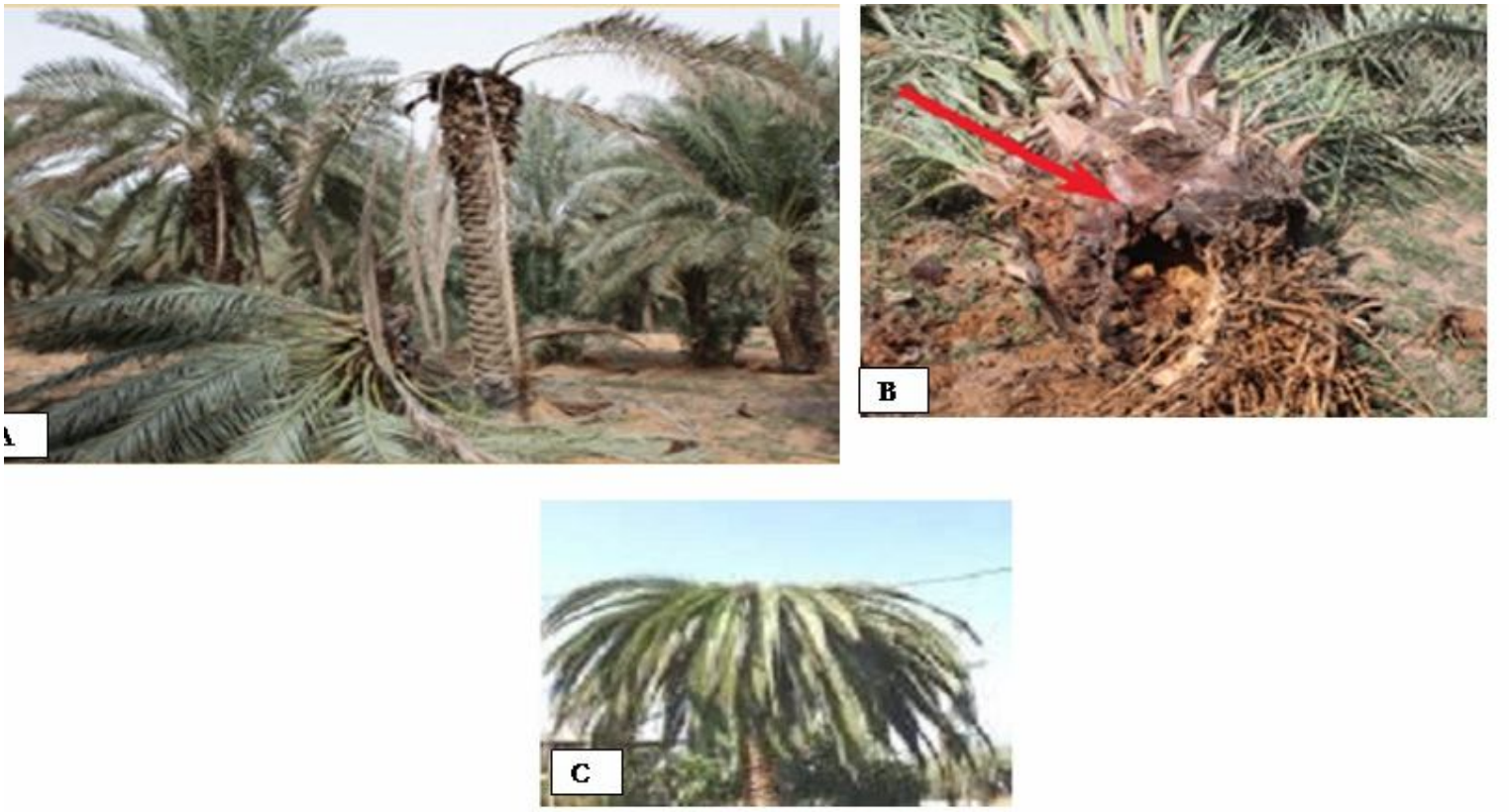

Figure (10): Symptoms of RPW infestation: A) severe level (III) of RPW infestation: a) toppled crown, B) removed young palm showing deep hollow cavity full of RPW stages, C) umbrella shape (Vidyasagar and Aldosary 2011).

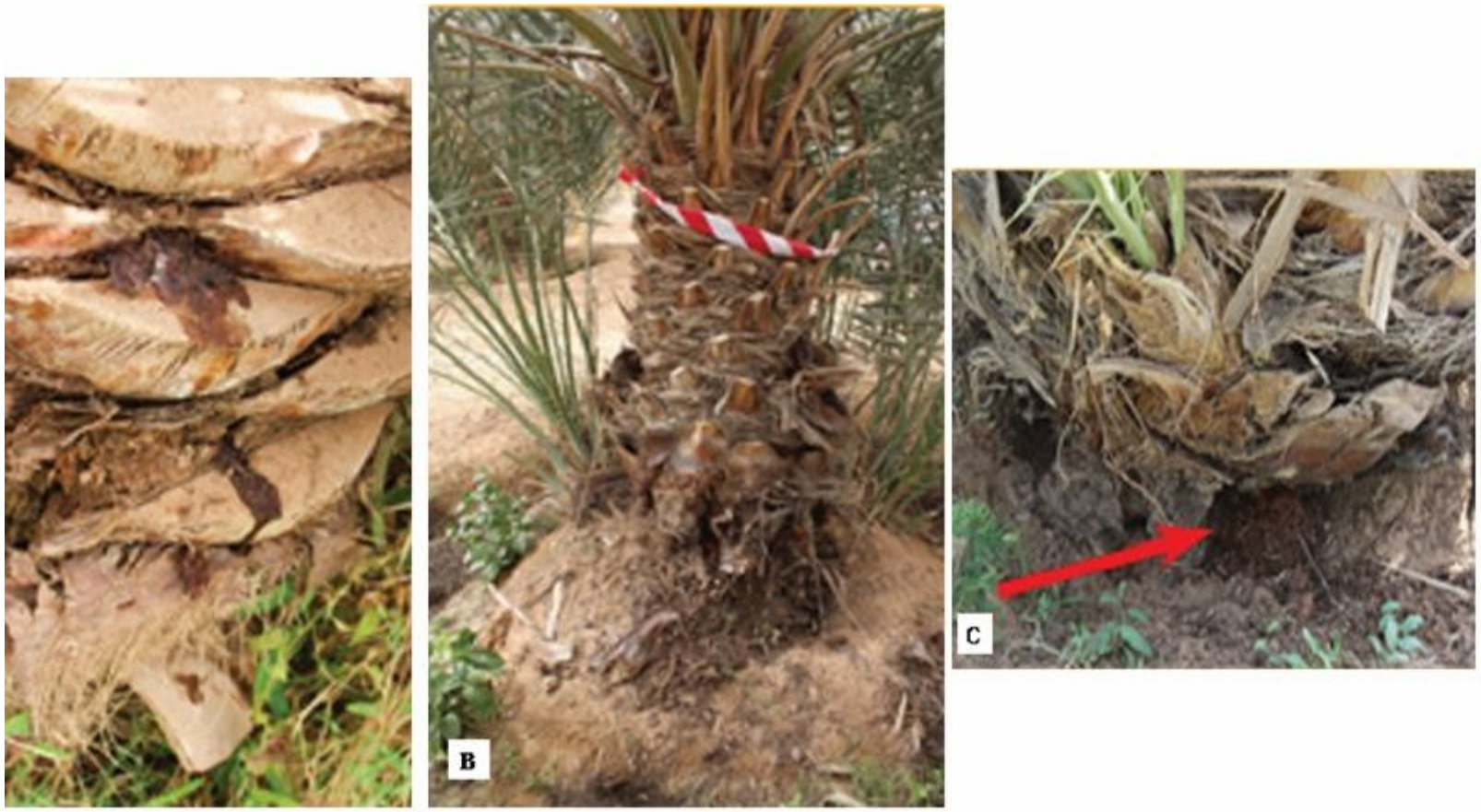

Figure (11): Symptoms of RPW infestation: a) brown viscous fluid oozing from the stem, B) Early (I) to medium (II) level of RPW infestation, C) young palm infested at the base (Vidyasagar and Aldosary 2011).

TABLES

Table (1): Palm weevils included in *Rhynchophorus* genus according to different authors.

Reference	***Rhynchophorus* spp.**
Herbst (1795)	22 species: 3 of them were true *Rhynchophorus:* *R. cruentatus* (Fabricius 1775), *R. ferrugineus* (Olivier) and *R. palmarum* (Linnaues 1764).
Lepesme (1947)	18 species: 7 among them attack palm trees: *R. cruentatus* (Fabricius 1775), *R. ferrugineus*, *R. kaupi* (Schaufuss 1764), *R. palmarum* (Linnaues 1764), *R. phoenicis* (Fabricius 1801), *R. quadrangulus* (Quedenfeldt 1888) and *R. signaticollis* (Chevrolat 1882).
Wattanapongsiri (1966)	10 species: **2 African:** *R. phoenicis* (Fabricius 1801) and *R. quadrangulus* (Quedenfeldt 1888). **5 tropical Asian:** *R. bilineatus* (Montrouzier), *R. distinctus* (Wattanapongsiri), *R. ferrugineus* (Olivier), *R. lobatus* (Ritsema) and *R. vulneratus* (Panzer). **3 New World:** *R. cruentatus* (Fabricius 1775), *R. palmarum* (Linnaues 1764) and *R. ritcheri* (Wattanapongsiri).

Table (2): Synonymous of some *Rhynchophorus* spp. (see Wattanapongsiri (1966) for references and details).

***Rhynchophorus* spp.**	**Synonymous**
R. *bilineatus* (Montrouzier)	*Calandra bilineata* (Montrouzie); *Sphenophorus palmarum* (Montrouzie); R. *kaupii* (Schaufuss); R. *velutinus* (Fairmaire); R.*pascha* var. papuanus (Kirsch); R. *rnontrouzieri* (Chevrola); R. *rubrocinctus* (Chevrolat); R. *bilineatus* (Montrouzier).
R. *cruentatus* (Fabricius 1775)	*Calandra cruentata* (Fabricius); R. *cruentatu* (Fabricius); *Curculio cruentatus* (Fabricius); R. *zimmermanni* (Fähraeu).
R. *distinctus* (Wattanapongsiri)	
R. *ferrugineus* (Olivier)	*Calandra ferruginea* (Fabricius); *Cordyle sexmaculatus* (Thunberg); *Curculio ferrugineus* (Olivier); *Curculio hemipterus* (Suizer); R. *indostanus* (Chevrola); R. *pascha var.* cinctus; R. *signaticollis* (Chevroia).
R. *palmarum* (Linnaues 1764)	*Curculio palmarum* (Linnaeus); *Calandra palrnarum* (Linnaeu); *Cordyle barbirostris* (Thunberg); *Cordyle palmarum* (Linnaeus); R. *barbirostris* (Thunberg); R. *cycadis* (Erichson); R. *depressus* (Chevrolat); R. *lanuginosus* (Chevrola).
R. *phoenicis* (Fabricius 1801)	*Calandra phoenicis* (Fabrlcius); R. *phoenicis (var.* Chevrolat, *var.* niger, *var.* ruber).
R. *vulneratus* (Panzer)	*Curculio vulneratus* (Panzer), R. *glabrirostris* (Schaufuss), R. *ferrugineus* (Olivier), R. *pascha* (Boheman), R. *schach* (Fabricius), R. *schach* (Schoenhe), *Calandra palmarum* (Linnaeus) and *Calandra schach* (Fabricius).

Table (3): Geographical distribution and host range of *Rhynchophorus* spp.

***Rhynchophorus* spp.**	**Host plant**	**Reference**	**Country**	**Reference**
R. bilineatus (Montrouzier)			Indonesia, New Guinea and Papua	see Wattanapongsiri (1966) for references and details
			New Guinea and Papua	Rugman-Jones *et al.* (2013)
R. cruentatus (Fabricius 1775)	*Sabal*, *Phoenix*	see Lepesme (1947) for references	New world: the West Indies, USA	see Wattanapongsiri (1966) for references and details
R. kaupi (Schaufuss 1764)	*Metroxylon sayu*	see Lepesme (1947) for references		
R. lobatus (Ritsema)		see Wattanapongsiri (1966) for references and details		

Table (3): Continue..

***Rhynchophorus* spp.**	**Host plant**	**Reference**	**Country**	**Reference**
R. palmarum (Linnaues 1764)	Acrocomia sclerocarpa (Attaleacohune), *Cococ coronala, Cococ nucifera, Cococ schizophylla, Elaeis guineensis, Guilielma* sp., *Gynerium saccharoides, Oreodoxa oleracea, Sabal umbraculifera*	see Lepesme (1947) for references		
	Acrocomia aculeate, *Acrocomia lasiopatha*, *Acrocomia sclerocarpa*, *Ananas sativa* (pine apple), *Attalea cohune (cohoon palm), Bactris major* (black reseau palm), *Carica papaya* (paw paw), *Cocos coronata*, *Cocos fusiformis*, *Cocos nucifera* (coconut palm), *Cocos romanzofiana*, *Cocos schizophylla*, *Cocos vagan*, *Desmoncus major* (picmoe palm), *Elaie guineensis* (oil palm), *Euterpe broadwayana* (manac palm), *Guilielma* sp., *Gynerium saccharoides, Jarracatia Dodecaphyll, Manicaria saccifera (timite palm), Maximiliana Caribaea (cocorite palm), Musa sapientum* (banana), *Oreodoxa olercea* (cabbage palm), *Ricinus* sp., *Sabal* sp. (carat palm), *Saccharum officinarum* (sugar cane).	see Wattanapongsiri (1966) for references and details	Cuba, The West Indies and Mexico	see Wattanapongsiri (1966) for references and details
R. phoenicis (Fabricius 1801)	Borassus aethiopum, *Elaeis guineensis, Hyphaene* sp., *Phoenix daclylijera, phoenix reclinata* and *Raphia vinifera*	see Lepesme (1947) for references		
	Cocos nucifera, Elaeis guineensis, Elaeis guieensis, Hyphaene sp., *Phoenix dactylifera, Phoenix reclinata, Borassus aethiopum* and *Raphia vinifera*	See Wattanapongsiri (1966) for references and details	Africa: Senegal, Kenya, the Union of South Africa, except Bechuanaland and Ethiopia New World: Brazil, Mexico	see Wattanapongsiri (1966) for references and details
R. quadrangulus (Quedenfeldt 1888)	*Elaeis guineensis*	see Lepesme (1947) for references	Africa: Angola, Congo and Guinea	see Wattanapongsiri (1966) for references and details

Table (3): Continue..

***Rhynchophorus* spp.**	**Host plant**	**Reference**	**Country**	**Reference**
R. ritcheri (Wattanapongsiri)			New World: Brazil and Peru	see Wattanapongsiri (1966) for references and details
R. signaticollis (Chevrolat 1882)	*Cocos nucifera* (coconut palm)	see Lepesme (1947) for references		
R. vulneratus (Panzer)	*Areca catechu* (Areca or betel nut), *Arenga saccharifera* (sugar or Kabong), *Cocos nucifera* (coconut palm), *Corypha genbaga* (gebong), *Elaeis guineensis* (African oil palm), *Levistonia cliochinchinensis* (serdang), *Metroxylon sagu* (sago palm), *Oncosperma horrida* (bagas), *Oncosperma tigillaria* (nibong), *Oreodoxa regia* (royal palm)	see Wattanapongsiri (1966) for references and details	Asie: Southern distribution across Indonesia, New World: USA Asia: Thailand, Malasia, Sumatra, Borneo, Malaya, Singapore, Borneo, Sumatra, Java, Timor, Celebes, Philippines and the East Indies Islands	Rugman-Jones *et al.* (2013) see Wattanapongsiri (1966) for references and details

Table (4): Geographical distribution and host range of RPW.

Country	Year	Reference	Host plant	Reference
Albania	2009	EPPO (2009a)		
Australia		Fitzgibbon (1999)	*Phoenix dactylifera* (Linn.)	Faleiro (2006a); Li *et al.* (2009)
			Saccharum officinarum	Fitzgibbon (1999); Malumphy and Moran (2009)
Australia (Victoria)		see Wattanapongsiri (1966) for references and details		
Bahrain	1985	Zaid *et al.* (2002)	*Phoenix dactylifera* (Linn.)	Zaid *et al.* (2002)
Bangladesh		CABI/EPPO (2010)		
Burma/Myanmar		CABI/EPPO (2010); see Wattanapongsiri (1966) for references and details		
Cambodia		CABI/EPPO (2010)		
Caribbean Islands	2008	EPPO (2009b)		
China	1990	CABI/EPPO (2010)	*C. nucifera*	Qin *et al.* (2002)
Croitia	2011	Masten-Milek and Simala (2013)		
Cyprus	2006	EPPO (2007a)	*Phoenix canariensis* (Chabaud)	EPPO (2007a)
			Phoenix dactylifera (Linn.)	
			Washingtonia filifera	

Table (4): Continue..

Country	Year	Reference	Host plant	Reference
Egypt	1992	Cox (1993)	*Phoenix dactylifera* (Linn.)	Cox (1993); EPPO (2006b)
France	2006	EPPO (2006b)	*Phoenix canariensis* (Chabaud) *Phoenix dactylifera* (Linn.)	
Georgia	2009	EPPO (2010a)	*Phoenix canariensis* (Chabaud) *Phoenix dactylifera* (Linn.) *Washingtonia filifera*	EPPO (2010a)
Greece	2005	Kontodimas *et al.* (2007)	*Phoenix canariensis* (Chabaud) *Washingtonia filifera*	Kontodimas *et al.* (2007)
India	1891	see Wattanapongsiri (1966) for references and details	*Borassu*	see Wattanapongsiri (1966) for references and details
Indonesia		CABI/EPPO (2010)	*s flabellifer (Linn.)* *C. nucifera* *Elaeis guineensis* *Phoenix dactylifera* (Linn.) *Arenga pinnata* (Wurmb.) *Borassus flabellifer* (Linn.) *Corypha gebanga (Mart.)* *Phoenix sylvestris* (Roxb.)	
Iran	1990	Faghih (1996)	*Phoenix dactylifera* (Linn.)	Faghih (1996)
Iraq		CABI/EPPO (2010)		
Israel	1999	Kehat (1999)	*Phoenix dactylifera* (Linn.)	Kehat (1999)

Table (4): Continue..

Country	Year	Reference	Host plant	Reference
Italy	2004	EPPO (2006a)	*Brahea armata* *Butia capitata* *Phoenix dactylifera* (Linn.)	EPPO (2006a)
Japan	2000	CABI/EPPO (2010)		
Japan (Kobe)		see Wattanapongsiri (1966) for references and details		
Jordan	1999	Kehat (1999)	*Phoenix dactylifera* (Linn.)	Kehat (1999)
KSA	1987	Ajlan and Abdulsalam (2000)	*Phoenix dactylifera*	Ajlan and Abdulsalam (2000)
Kuwait	1993	Zaid *et al.* (2002)	*Phoenix dactylifera*	Zaid *et al.* (2002)
Laos		CABI/EPPO (2010)		
Lebanon	2010	CABI/EPPO (2010)		
Libya	2009	EPPO (2010b)		
Malaysia	2007	Azmi *et al.* (2013)	*Cocos nucifera*	Azmi *et al.* (2013)
Malta		CABI/EPPO (2010)		
Mesopotamia	1918	see Lepesme (1947) for references		

Table (4): Continue..

Country	Year	Reference	Host plant	Reference
Morocco	2008	EPPO (2009b)	*Phoenix canariensis* (Chabaud)	EPPO (2009b)
Oman	1985	Kaakeh *et al.* (2001)	*Phoenix dactylifera* (Linn.)	Kaakeh *et al.* (2001)
Pakistan		Laskshmanan *et al.* (1972) (as cited in Faleiro (2006a))		
Palestine	1999	Kehat (1999)	*Phoenix dactylifera* (Linn.)	Kehat (1999)
Papua New Guinea		El-Ezaby (1997)		
Philippines		CABI/EPPO (2010); see Wattanapongsiri (1966) for references and details	*Areca catechu* *Arenga pinnata* *Borassus flabellifer* *Caryota maxima* *Caryota cumingii* *Corypha elata* *Cocos nucifera*	see Wattanapongsiri (1966) for references and details
Portugal	2007	EPPO (2008)a	*Phoenix canariensis*	EPPO (2008)
Qatar	1985	Zaid *et al.* (2002)	*Phoenix dactylifera* (Linn.)	Zaid *et al.* (2002)
Samoa Island		CABI/EPPO (2010)		
Singapore				
Slovenia				
Solomon Island				

Table (4): Continue..

Country	Year	Reference	Host plant	Reference
Spain-Canary Islands	2006	EPPO (2008b)	*Phoenix canariensis*	EPPO (2008b)
Spain-mainland	1993	Barranco *et al.* (1996) (as cited in Murphy and Briscoe (2002))	*Chamaerops humilis*	Barranco *et al.* (1996) (as cited in Murphy and Briscoe (2002))
			Phoenix canariensis	Esteban-Duran *et al.* (1998)
			Phoenix theophrasti	Barranco *et al.*, 1996 (as cited in Murphy and Briscoe (2002))
Sri Lanka (Ceylon)		CABI/EPPO (2010)		
Syria	2005	EPPO (2007b)		
Thailand		see Wattanapongsiri (1966) for references and details	*Phoenix dactylifera*	see Wattanapongsiri (1966) for references and details
Taiwan			*Bismarckia nobillis*	Liao-Chung (1997)
			Phoenix canariensis	
Turkey	2005	EPPO (2007b)	*Phoenix dactylifera* (Linn.)	EPPO (2007b)
Tunisia	2011	EPPO (2011a)		
UAE	1985	Zaid *et al.* (2002)	*Phoenix dactylifera*	Zaid *et al.* (2002
Vanuato		CABI/EPPO (2010)		
Vietnam		see Wattanapongsiri (1966) for references and details		
Yemen	2013	EPPO (2014)	*Phoenix dactylifera* (Linn.)	EPPO (2014)
			Agave Americana	Hussain *et al.* (2013)
			Corypha umbraculifera	Abraham *et al.* (1998)

Table (5): Biological parameters of RPW: life cycle duration. a, b & c: Modified from Dembilio and Jacas (2012). *female reared without males. **averages.

Feeding material	Stage duration (days)				Adult longevity (days)		Life cycle (days)	Reference
	Egg	Larva	Prepupa	Pupa	Male	Female		
Apple slices	4.9	103	14	17	31	38	170-177	Salama *et al.* (2009)
	4-5							Shahina *et al.* (2009)
Artificial diet		69						Al-Ayedh (2011)
		16						El-Sebay *et al.* (2003)
	3-4	70-102		16-23			93-131	Kaakeh (2005)
		91		21	49	45	107	Kaakeh *et al.* (2001)
	3-4	93		30			128	Martin-Molina (2004) (as cited in Dembilio and Jacas (2012))
		96.7		21.1			119.4	Sharaby and Al-Dhafar (2013)**
Banana slices				13-22				Salama *et al.* (2002)
	4.9	90	9	18	39	38	161	Salama *et al.* (2009)
Coconut tissue						51-99		Faleiro (2005)*
					54-78	47-100		Faleiro (2005)
	3	99		20	65	68		Kaakeh (2005)
	2-5	36-67		12-21			54-120	Nirula (1956) (as cited in Wattanapongsiri (1966))

Table (5): Continue..

Feeding material	Duration (days)				Adult longevity (days)		Life cycle (days)	Reference
	Egg	Larvae	Prepupae	Pupae	Male	Female		
Coconut tissue	3	35-38		11-19			49-70	Viado and Bigornia (1949) (as cited in Wattanapongsiri (1966))
Honey in cotton	4-5							Shahina *et al.* (2009)
Oat	3	91		21	49	44		Kaakeh (2005)
Oat palm fiber sheath	3	101		23	77	73		Kaakeh (2005)
Oat pineapple	3	102		22	69	72		Kaakeh (2005)
Oat potato	3	99		20	65	68		Kaakeh (2005)
Palm crown lumps	4.9	69	12	18	42.6	42.7	147	Salama *et al.* (2009)
Palm tissues						56-76		Abbas and Al-Nasser (2012)
Palm lumps	1-6	41-78		15-72	39 –72	20-120	57-111	Faghih (1996)
Palm lumps	2-4	25-135		17-50			48-225	Ghosh (1912, 1923, 1940)(as cited in Wattanapongsiri (1966)).
Palm heart lumps	3-4	86		21			124	Kaakeh (2005)
Palm leaf base	3-4	84		18			119	Kaakeh (2005)
Palm lumps								Martin-Molina (2004) (as cited in Dembilio and Jacas (2012))
Phoenix canariensis	2-18	40-160		13-several months				Dembilio and Jacas (2011)
Pineapple	3	75		18	57	51		Kaakeh (2005)
Potato	3	70		16	51	53		Kaakeh (2005)

Table (5): Continue..

Feeding material	Duration (days)				Adult longevity (days)		Life cycle (days)	Reference
	Egg	Larva	Prepupa	Pupa	Male	Female		
Sago palm tissue							105-210	Kalshoven (1981)
		60		13-15			73-75	Leefmans (1920) (as cited in Wattanapongsiri (1966))
Squash fruit	4-9	83	15	22	33	40	159-165	Salama *et al.* (2009)
Sugarcane tissue	3-5	40-73	3-4	16-27	40-70		90	Abbas and El Sebay (2013)
	3-5	86-90		20-21			120-125	A.-Fetouh (2011)
	2-4	24-61		18-34			44-100	Butani (1975)
		76-102		11-45			45-139	Esteban-Duran *et al.* (1998)
		81-89						Jaya *et al.* (2000)
	3-4	82		19	29-35	33-41	108	Kaakeh (2005)
		62		19	76	84	107	Kaakeh *et al.* (2001)
	3-4	88		25			116	Martin-Molina (2004) (as cited in Dembilio and Jacas (2012))
		32-75						Prabhu and Patil (2009)
	3-4	32-51		15-28			50-82	Rahalkar *et al.* (1972)
	4-9	128	17	27	32	37	209-214	Salama *et al.* (2009)
	4-5	50-80		20-30			74-115	Shahina *et al.* (2009)

Table (5): Continue.

Feeding material	Duration (days)				Adult longevity (days)		Life cycle (days)	Reference
	Egg	Larva	Prepupa	Pupa	Male	Female		
Sugarcane tissue Unidentified	2-4	32-65	4-10	10-21	62-78	59-75 86-98	58-97	Paddy (2009) Abraham *et al.* (2001)
		165-182					165-182	Aldhafer *et al.* (1998)
		60-241	6-20		67-257	70-150	158-298	Alsuhaibani *et al.* (2001)
	7	28-42		14-21			48-112	Butani (1975)
		69		23 - 27	67 - 91	68- 112	101-128	El-Ezaby *et al.* (1998)
		36-78			60 – 90			Frohlich and Rodewald (1970)
	3						60-120	Gunawardena and Gunatilake (1993)
	2-5	35-129 summer-winter		14			60-90	Hussain *et al.* (2013)
	3	60		15			90-180	Lepesme (1947)
		48.43-55.69						Ramachandran (1998)
	3-4	25-105	2-11	11-33			45-165	See Wattanapongsiri (1966) for references

Table (6): Biological parameters of RPW: numbers of instars, egg production, hatching % and average egg production.

Feeding material	No. of larval instar	Egg production	Hatching %	Average egg production /day	Reference
Apple slices	13				Abe *et al.* (2009)
	12	204-262	60	6.12	Salama *et al.* (2009)
	4				Shahina *et al.* (2009)
Artificial diet	11	338	0.86 ± 0.10		Al-Ayedh (2011)
		66	76	2.1	Kaakeh *et al.* (2001))
	7-12				Martin-Molina (2004) (as cited in Dembilio and Jacas (2012))
	7-12				Rahalkar *et al.* (1985)
	15	250.2±52.1	82.7		Sharaby and Al-Dhafar (2013)
Banana slices	5				Salama *et al.* (2002)
		238-307	85	7.11	Salama *et al.* (2009)
Coconut tissue		40-328	50-55		Faleiro (2005)*
.		119-362	61-78		Faleiro (2005)
	9				Kaakeh (2005)
	3				Nirula (1956) (as cited in Wattanapongsiri (1966))
	9				Viado and Bigornia (1949)(as cited in Wattanapongsiri (1966))
Honey in Cotton	4				Shahina *et al.* (2009)

Table (6): Continue..

Feeding material	No. of larval instar	Egg production	Hatching %	Average egg production/day	Reference
Oat	4	135	78		Kaakeh (2005)
Oat palm fiber sheath		102	75		Kaakeh (2005)
Oat pineapple		97	80		Kaakeh (2005)
Oat potato		92	78		Kaakeh (2005)
Palm crown lumps		301-375	83	7.92	Salama *et al.* (2009)
Palm heart lumps	5				Kaakeh (2005)
Palm lumps	8-15	3 - 206			Faghih (1996)
Palm lumps		300			Ghosh (1912, 1923, 1940)(as cited in Wattanapongsiri (1966))
Palm lumps	8-15				Martin-Molina (2004) (as cited in Dembilio and Jacas (2012))
Palm leaf base		128	86		Kaakeh (2005)
Palm tissues		60-78			Abbas and Al-Nasser (2012)
	10	332	0.60 ± 0.10		Al-Ayedh (2011)
		220-261			Abbas and Al-Nasser (2012)
Palm trunk		33	0.60 ±0.10		Al-Ayedh (2008)
Phoenix canariensis	13				Dembilio and Jacas (2011)
Pineapple		77	73		Kaakeh (2005)
Potato		68	80		Kaakeh (2005)

Table (6): Continue..

Feeding material	No. of larval instar	Egg production	Hatching %	Average egg production /day	Reference
Squash fruit		246-295	81	6.75	Salama *et al.* (2009)
Sugarcane tissue		130-220	Max. 90		Abbas and El Sebay (2013)
	11				El-Sebaay *et al.* (2003)
	7				Esteban-Duran *et al.* (1998)
	7				Jaya *et al.* (2000)
	9	185	74.3		Kaakeh (2005)
	11-17				Martin-Molina (2004) (as cited in Dembilio and Jacas (2012))
	8-9				Prabhu and Patil (2009)
		204	79		Rahalkar *et al.* (1972)
	10	98-136	52	3.16	Salama *et al.* (2009)
	9				Shahina *et al.* (2009)

Table (6): Continue..

Feeding material	No. of larval instar	Egg production	Hatching %	Adult emergence %	Reference
Sugarcane tissue	8	211-380	70-90	85-90	Paddy (2009)
Unidentified		152-330	54-72		Abraham *et al.* (2001)
		55-412			Aldhafer *et al.* (1998)
		55-500	30-40		Alsuhaibani *et al.* (2001)
					Butani (1975)
		18 -383	45 - 55		El-Ezaby *et al.* (1998)
		204	30 - 50		Frohlich and Rodewald (1970)
		123			Gunawardena and Gunatilake (1993)
	16	349			Hussain *et al.* (2013)
					Lepesme (1947)
	10	127-531	86-94		See Wattanapongsiri (1966) for references

Table (7): Effects of feeding materials on different RPW stages weight. (1) Al-Ayedh (2011), (2) Mogahed (2010), (3) Salama *et al.* (2009), (4) Paddy (2009).

Feeding material	Weight (mg or g)				
	Larvae	Prepupa	Pupae	Adult male	Adult female
Artificial diet (1)				0.94g	1.05g
Banana sices (3)	1st: 0.1520-0.1690g 2nd: 0.9341-0.9421g 3rd: 0.1580-1.328g 4th: 2.6466-2.6832g 5th: 4.2111-4.9234g	3.0334-4.2111g	4.1945-4.9140g	1.9670-2.3466g	1.8991-2.4390g
Date Palm, *Phoenix dactylifera* (2)	19.22-19.38mg				
Fig, *Ficu scarica* (L.) (2)	6.16mg				
Guava, *Psidium guava* (L.) (2)	5.94mg				
Lime, *Citrus medica medica* var. *Limonum* (R.) (2)	1.02mg				
Mandarin, *Citrus aurantium* var. *deliciosa*(L.) (2)	0.98mg				
Mango, *Mangifera indica* (L.) (2)	6.30mg				
Olive, *Olea sativa* (Hoffmgg) (2)	1.06mg				
Palm Tissues, *Phoenix dactylifera* (2)				0.74g	0.95g
Sour Orange, *Citrus aurantium* var. *amara* (L.) (2)	0.86mg				
Sugarcane (3)	1st: 0.1333-0.1605g 2nd: 0.8400-09381g	3.8990-4.2570g	4.3450-5.2111g	0.6902-2.1904g	0.7103-2.1904g
Sugarcane (4)	4-6.4		1.45-3	0.53	1.09

Table (8): Effects of feeding materials on different RPW morphological parameters.

Feeding material	Length (mm)			Width (mm)		Reference
	Pupa	Male	Female	Male	Female	
Artificial diet	31.9	28.6	30.38	9.75	9.75	Al-Ayedh (2011)
Coconut	35	35	12	12	12	Nirula (1956)
	33.5	39	41.5	13.4	14.6	Viado and Bigornia (1949)
Sugarcane	33.75	29.95	32.23	9.75	9.75	Al-Ayedh (2011)
		33.50	34.40	11.50	11.70	Paddy (2009)

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Table (9): Effects of feeding materials on different RPW biological parameters (Mogahed 2010).

Feeding material	Food consumption %	Larval mortality %	Adult emergence %	Pupation rate
Date palm, *Phoenix dactylifera*	Highest 100%	Lowest 0%	Highest 95.6-96.2%	Highest 100%
Mango, *Mangifera indica*(L.)	11-25%			
Guava, *Psidium guava*(L.)	11-25%			
Fig, *Ficu scarica* (L.)	11-25%			
Olive, *Olea sativa* (Hoffmgg)	1-10%			
Lime, *Citrus medica medica* Var. *limonum* (R.)	1-10%			
Mandarin, *Citrus aurantium* var. *Deliciosa* (L.)	1-10%			
Olive, *Olea sativa*				
Sour orange, *Citrus aurantium* var. *amara* (L.)	Lowest traces	Highest	Lowest	Lowest

Table (10): RPW infestation levels of different palm varieties.

Variety	Percentage of Infestation (%)	Country	Reference
Agalani	23.73	Egypt	Salama *et al.* (2009)
Amhat	6.3	Egypt	El-Lakwah *et al.* (2011)
Amri	5.6	Egypt	Salama *et al.* (2009)
Aseel	21.4	Pakistan	El-Lakwah *et al.* (2011)
Bent-Eisha	7.28	Egypt	Salama *et al.* (2009)
Hyani	6.9	Egypt	El-Lakwah *et al.* (2011)
	18.13	Egypt	Salama *et al.* (2009)
Kaboushi	1.53	Egypt	Salama *et al.* (2009)
Khurmo	14.5	Pakistan	El-Lakwah *et al.* (2011)
Mogahel	80.90	Egypt	Salama *et al.* (2009)
Samani	9.7	Egypt	El-Lakwah *et al.* (2011)
	39.73	Egypt	Salama *et al.* (2009)
Seedling	13	Egypt	El-Lakwah *et al.* (2011)
Zaghloul	11.7	Egypt	El-Lakwah *et al.* (2011)
	13.79	Egypt	Salama *et al.* (2009)

Table (11): Temperature of healthy and RPW infested palm and the surrounded environment.

Month	Country	Note	Infested palm (°C)	Healthy palm (°C)	Outer temperature (°C)	Reference
			30-40			Abe *et al.* 2010
			25.03- 37.39	22.40- 36.59	13.83- 48.66	Mozib and El-Shafie (2013)
August	Egypt		27.4-29.3	27.2-28.9	29.5-34.2	Salama *et al.* (2009)
		Meteorological station	33.3		39.9	
September			25.4-26.7	26.1-27.4	28-29.5	
December-January			16.1-18.7		16.5-21.9	
February			12-16.2		16.1-20.4	

Table (12): Effects of temperature (10-25°C) on fecundity rate, ovopostion rate and percentage of hatchability of RPW at laboratory (Dembilio *et al.* 2011a).

Temperature	Oviposition rate (egg(s) per female & day)	Fecundity rate (egg(s) per female)	Egg hatching (%)
25°C	highest 2.38	highest 33.25	highest 75.5 in 2 days
23°C	1.88	26.25	71.8
Moved from 25°C to 23°C at 14 days old	1.82	25.50	75.8
20°C	0.88	13.08	65.8
Moved from 25°C to 20°C at 14 days old	0.55	7.67	71.7
<15°C	0		
15°C	0		
Moved from 25°C to15°C at 14 days old	0.37	5.17 (during 15 days) 84% reduction	60.5 in 18 days
10°C	0		
10°C			0
Moved from 25°C to10°C at 14 days old	0.05	0.75 (during 2 days) 98% reduction	12.5 83.5% reduction

Salama *et al.* (2002)

	Optimal thermal threshold (°C)	Highest threshold (where they are killed) (°C)
Pupa	26.6-29.5	44-45

Table (13): The thermal cumulated degree days (DD) for the development of different RPW stages, the lower temperature threshold (LTTs) for different RPW stages, fecundity, ovipositin and egg hatching.

	DD	LTT	Notice	Reference
Egg	40.4	13.1	laboratory	Dembilio and Jacas (2011)
		13.1		Martin-Molina (2004) (as cited in Dembilio and Jacas (2012))
		10		Salama *et al.* (2002)
Larvae	666.5	5 neonate 4.5 immature	40 days in summer & 160 days in winter-spring, depending on the mean temperature, in *P. canariensis*.	Dembilio and Jacas (2011)
	1.106	15 5	in laboratory.	Martin and Cabello (2006) (as cited in Dembilio and Jacas (2012))
		15		Martin-Molina (2004) (as cited in Dembilio and Jacas 2012)
		5		Salama *et al.* (2002)
Pupae	282.5		in *P. canariensis*. 13 days in the summr and several months in the rest of the year.	Martin and Cabello (2006) (as cited in Dembilio and Jacas (2012))
	328	13		
		13		Martin-Molina (2004) (as cited in Dembilio and Jacas (2012))
	423	-2.3	can be repeated 20.7 times.	Salama *et al.* (2002)
Adult				Dembilio and Jacas (2011a)
Oviposition		15.45		Dembilio *et al.* (2011a)
		16.48		Li *et al.* (2010)
Fecundity		15.35		Dembilio *et al.* (2011a)
Hatching		13.1		Dembilio and Jacas (2011)
		13.95		Dembilio *et al.* (2011a)
		13.95		Kaakeh (2005)
		18.28		Li *et al.* (2010)

Table (14): Oviposition and egg hatching periods based on mean monthly temperatures in the Mediterranean basin (Dembilio *et al.* 2011a).

Country	Area	Oviposition period *	Hatching period *
	Adana	March to November	April to October
Egypt	**Alexandria**	March to December	January to December
	Algiers	April to December	February to December
	Almeria	March to November	March to December
Greece	**Athens**	April to October	April to October
Libya	**Benghazi**	February to December	January to December
	Cagliari	April to October	half March to November
	Iraklion	April to November	March to December
Turkey	**Istanbul**	April to November	April to November
France	**Marseille**	April to October	March to October
	Melilla	March to November	February to December
	Palermo	April to November	March to December
Italy	**Rome**	April to September	April to October
	Split	April to October	March to October
Israel	**Tel-Aviv**	February to November	January to December
	Tripoli	March to October	March to November
	Valencia	April to October	March to October

* See (Dembilio *et al.* 2011a) for the exact period within each month please.

Table (15): Pupal duration and rate of weevil emergence in Egypt (Salama *et al.* 2002).

Month	Temperature (°C)	Pupal duration (days)	Rate of weevil emergence (cycles)
January	14	25.9	1.19
February	15	24.2	1.19
March	17.1	21.8	1.42
April	20.3	18.7	1.60
May	24.1	16.0	1.93
June	26.6	14.6	2.05
July	28.5	3.14	2.3
August	29.3	3.14	2.3
September	27	14.4	2.08
October	23.8	16.2	1.91
November	19.5	19.4	1.55
December	15.2	24.2	1.28

Table (16): Maximum and minimum RPW adult activity in different countries.

Country	RPW maximum activity	RPW minimum activity	Reference
Egypt	March, August, & October		Abbas (2013)
	March-May September-November	The other months	Abbas and Al-Nasser (2012)
	March & October		
	March & April		El-Ezaby *et al.* (1998)
	April & June		El Garhy (1996)
Goa	October & November	June & July	Faleiro (2005)
India		March, May & December	Muralidharan *et al.* 2000 (as cited in Abbas (2013)) ; Vidyasager *et al.* (2000)
Israel	April & June		Soroker *et al.* (2005)
Italy	March-November	December-Februry	Conti *et al.* (2013)
KSA	January - May	July-December	Hoddle et al. (2013)
	March & April		Vidyasagar *et al.* (2000)
	May		Ajlan and Abdulsalam (2000); Faleiro (2006b); Vidyasagar *et al.* (2000)
	November		Faleiro (2006b)
	June		Massoud *et al.* (2012)
		February, August & October	Ajlan and Abdulsalam (2000); Faleiro (2006b)
Oman	March, May, August & October	December & January	Al-Khatri and Abdallah (2003)
UAE	March & April	September	Al-Saoud and Ajlan (2013)
	March, April & May		UAEIR (2006)

Table (17): Geographical distribution of RPW CO1 haplotypes.

Haplotype	Country	Haplotype	Country	Haplotype	Country	Haplotype	Country	Haplotype	Country
El-Mergawy H1	Oman*	El-Mergawy H8	Curacao#	**H9**	India#	**H21**	Thailand#	**H32**	Cambodia#
	Pakistan*		Cyprus*	**H10**	Sri Lanka#	**H22**		**H33**	Cyprus#
	Syria*		Egypt*	**H11**	India#	**H23**	Philippines#	**H34**	Cambodia#
	UAE*		France*	**H12**	Sri Lanka#	**H24**		**H35**	Vietnam#
El-Mergawy H2	Iran*		Greece*	**H13**		**H25**		**H36**	
El-Mergawy H3	UAE*		Israel#	**H14**	India#	**H26**		**H37**	Vietnam#
El-Mergawy H4	UAE*		Italy*	**H15**		**H27**		**H38**	
El-Mergawy H5	Oman*		KSA*	**H16**		**H28**		**H39**	
	Pakistan #		Malaysia#	**H17**	Israel#	**H29**		**H40**	
			Portugal#		KSA#	**H30**		**H41**	
	UAE*		Spain-Canary Islands*	**H18**	Thailand#	**H31**		**H42**	
El-Mergawy H6	Oman*		Spain-Mainland*	**H19**	Malaysia#			**H43**	Thailand#
El-Mergawy H7	Japan*		Thailand#		Thailand#				
			Turkey*	**H20**	Aruba#				

Different shadings refer to different phylogenetic groups.

* El-Mergawy (2012, 2013); El-Mergawy *et al.* (2011c)

Rugman-Jones *et al.* (2013)

Table (18): Isolated natural enemies of RPW.

Natural enemy		Country (s) of record	Reference
Type	**Scientific name**		
Bacterium	*Bacillus* spp.	India	Banerjee and Dangar (1995)
	B. laterosporus	Egypt	Salama *et al.* (2004)
	B. megaterium	Egypt	Salama *et al.* (2004)
	B. shaericus	Egypt	Salama *et al.* (2004)
	B. sphaericus	Egypt	Alfazarity (2003); Alfazarity *et al.* (2004)
	B. thuringiensis	Egypt	Alfazarity (2003); Alfazarity *et al.* (2004)
	Coryneform group	India	Banerjee and Dangar (1995)
	pseudomonas aeruginosa	India	Banerjee and Dangar (1995)
	p. aeruginosa	Kerala	Banerjee and Dangar (1995)
	Serratia spp.	India	Banerjee and Dangar (1995)
Bird	*Dendrocitta vagabunda parvula*		Krishnakumar and Sudha (2002)
	Chelisoches moris		Abraham and Kurian (1973)
	Scolia erratica		Nirula (1956)
Fungus	*Beauveria* spp.	India	Shaju *et al.* (2003)
	B. bassiana	Iran	Ghazavi and Faghih (2002)
	B. bassiana	Spain	Guerri-Agullo *et al.* (2010, 2011)
	B. bassiana	UAE	Al-Naeemy (2012)
	B. bassiana		Dembilio *et al.* (2010)
	Metarhizium spp.	KSA	Vidyasagar and Aldosary (2011)
	M. anisopliae	Iran	Ghazavi and Faghih (2002)
	M. anisopliae		Gindin *et al.* (2006)
	M. pingshaense		Cito *et al.* (2014)
	Praecocilenchus ferruginophorus	India	Rao *et al.* (1980)
	P. ferruginophorus	Kerala	Rao *et al.* (1980)

Table (18): Continue..

Natural enemy		Country of record	Reference
Type	**Scientific name**		
Insects	*Chelisoches morio* (Dermaptera)	India Kerala	Abraham and Kurian (1975)
	Scolia erratica (Hymenoptera)	Indonesia Java	Peter (1989)(as cited in Murphy and Briscoe (1999))
		Singapore	See Wattanapongsiri (1966) for references
	Paratheresia menezesi (Diptera)		
	P. rhynchophorae (Diptera)		
	Sarcophaga fuscicauda (Diptera)	India	Peter (1989) (as cited in Murphy and Briscoe (1999))
		India	Venkatasubbaiyer (1940)(as cited in Murphy and Briscoe (1999))
		India	Iyer 1940; Peter 1989 (as cited in Murphy and Briscoe (1999))
		Kerala	Iyer (1940)(as cited in Murphy and Briscoe (1999))
Mites	*Centrouropoda almerodai*	Italy	Mazza *et al.* (2011a)
	Hypoaspis spp.	India Tamil Nadu	Peter (1989) (as cited in Murphy and Briscoe (1999))
	Laelapidae		
	Parasitidae	India	Sathiamma (1995)
	Pymotidae		Peter (1989) (as cited in Murphy and Briscoe (1999))
	Rhynchopolipus rhynchophori		Abdullah (2009b)
	Tetrapolypus rhynchophori		Peter (1989) (as cited in Murphy and Briscoe (1999))
	Uropodidae	India	Sathiamma (1995)
	Uropodidae	Philippines	
	Uropodidae	Sri-Lanka	

Table (18): Continue..

Natural enemy		Country of record	Reference
Type	**Scientific name**		
Nematode	*Heterorhabditis* spp.	Egypt	Salama and Abd-Elgawad (2001)
		UAE	Al-Naemy (2012)
	H. indicus	Egypt	Abbas *et al.* (2001a, 2001b, 2001c)
		India	Sosamma and Rasmi (2002)
		KSA	Liacer *et al.* (2009)
		UAE	Abbas *et al.* (2001a)
		UAE	
	Praecocilenchus ferruginophorus	India	Rao *et al.* (1980)
		Kerala	
	Rhabditis spp.	India	Banu and Rajendran (2002, 2003)
	Rhynchopolipus rhynchophori	Egypt	Abdullah (2009b)
	Steinernema abbasi	Egypt	Abbas *et al.* (2001a, 2001b, 2001c)
	Steinernema glaseri	India	Banu *et al.* (2003)
	Steinernema spp.	India	Sosamma and Rasmi (2002)
	Teratorhabditis palmarum	India	
	Steinernema abbasi	UAE	Abbas *et al.* (2001b, 2001c)
	Steinernema yiobravis	UAE	Al-Naemy (2012)
	Steinernema carpocapsea	Spain	Dembilio and Jacas (2013); Dembilio *et al.* (2011b); Liacera *et al.* (2009)
Virus	Cytoplasmic Polyhedrosis Virus (CPV)	Egypt	Gobinadhan *et al.* (1990)
		India	
		Kerala	
Yeast		Egypt	Salama *et al.* (2004)
		India	Dangar (1997)

Table (19): Different kairomones approved to attract RPW.

Kairomone	Reference
ferrmentation volatiles oozing from wounded coconut palms	(Gunatilake and Gunawardena 1986; Gunawardena and Gunatilake 1993; Kalshoven 1981; Kurian *et al.* 1979, 1984; Loqma and Alqaeit 2002; Maharaj 1973)
coconut petioles	(Faleiro and Satarker 2003b; Faleiro *et al.* 1998)
date palm stems, petioles or fruits	(Abraham *et al.* 1998; Faleiro *et al.* 1998; Sivapragasam *et al.* 1990)
sugarcane	(El Garhy 1996)
coconut logs treated with toddy, yeast & acetic acid	(Kurian *et al.* 1984)
a mixture of ethyl acetate, molasses,ethylene glycol & water	(Fiaboe *et al.* 2011; Roda *et al.* 2011)
a mixture of ethyl acetate/molasses/water/ethylene glycol & N-pentanol (a major alcohol constituent of coconut saps)	(Gunawardena and Herath 1995; Jaffe *et al.* 1993; Samarajeeva and Adams 1983)
Ethyl acetate & biotrat propionate	(Gunawardena and Bandarage 1995)
ethyl acetate	(Al-Saoud 2013)
synthetic palm ester	(Guarino *et al.* 2011)

Table (20): Different trapping densities.

Trap Densities	Reference	Note
1 trap/100 ha	Abraham *et al.* 2000	Pest free area
1 trap/1.5 ha		Pest free area
10 trap/ha	Abraham *et al.* 2000; Soroker *et al.* 2005	
1 trap/ha	Faleiro *et al.* (2011)	in plantation with low weevil activity and infestation less than 1%
10 trap/ha	Faleiro *et al.* (2011)	in plantation with infestation level more than 1%
4-7 trap/ha	Faleiro *et al.* (2011)	depending on the available resources
1 trap/100ha	Anonymous 2004a	Egypt
0.5 trap/ha	Anonymous 2004b	
1-2 traps/ha	Faleiro and Satarkar (2003c)	Goa
a limited time and period in the year	Aggelakopoulos *et al.* (2014)	Greece
10 traps/1-3ha	Faleiro 2005; Soroker *et al.* 2005	Israel
1 trap/ha		Israel
1 traps/1-50ha	Soroker *et al.* (2013)	Israel
0.3-0.9 trap/h	Hoddle *et al.* (2013)	KSA
16 traps/200 trees/ha	Ajlan and Abdulsalam (2000)	KSA

Table (21): Sex percentage of attracted weevils.

Male:female %	Reference
1:2	Abbas (2013); Al-Saoud and Ajlan (2013); Faleiro (2005)
0.5:1	Abbas and Al-Nasser (2012)
1:1.8	Abdallah and Al-Khatri (2005); Faleiro and Chellapan (1999)
1:2.4	Abraham *et al.* (1999)
1:3.1	Abraham *et al.*, (1999)
1:2.4	Al-Saoud (2013)
0.7:1	Hoddle *et al.* (2013)
1: 0.44	Rao and Sujatha (2004)

Table (22): Chemical Products tested and/or used against RPW.

Chemical product	Reference	Note
Acephate (O,S-Dimethyl acetylphosphoramidothioate)	Cabello *et al.* (1997)	
Aflix (endosulfan + dimethoate)	Azam and Razfi (2001)	
aluminum phosphide 57% (Phostoxin)	Abbas (2013); Liacer and Jacas (2010)	
Annona	Azam and Razfi (2001)	
Anthio	Azam and Razfi (2001)	
Azadirachtin (Azt): neem seeds extract	Barranco *et al.* (1996); Bream *et al.* (2001)	
Azinphos-methyl (O,O-Dimethyl-S-4-oxo-1,2,3-benzotriazin-3(4 H)-ylmethyl phosphorodithioate	Soroket *et al.* (2005)	Preventive-trunk sprays
Benzene hexachloride (BHC) (5%)	Kurian and Mathen (1971) (as cited in Faleiro (2006a))	
Basudin (diazinon, 3 ml/1 liter)	Abbas (2013)	
Beta- cyfluthrin	Cabello *et al.* (1997)	
Carbaryl (1-naphthyl n-methylcarbamate)	El Ezaby *et al.* (1998); Kurian and Mathen (1971); Lakshmanan *et al.* (1972); Mathen and Kurian (1967); Rao *et al.* (1973)	
Cidial (phenthoate, 3ml/1 liter)	Abbas (2013)	
Chlorpyriphos (diethyl O-(3,5,6-trichloro-2-pyridyl)phosphorothioate)	Abraham *et al.* (2000); Ferry and Gómez (2002); Murphy and Briscoe (1999); Soroker *et al.* (2005)	Preventive-trunk sprays
Deltamethrin	Cabello *et al.* (1997)	

Table (22): Continue..

Chemical product	Reference	Note
Diallyl Disulphide (synthetic oil)	Murthy and Amonkar (1974)	
Diazinon (O,O-Diethyl O-(2-isopropyl-6-methyl-4-pyrimidinyl) Phosphorothioate	Murphy and Briscoe (1999); Soroker et al. (2005)	Preventive-trunk sprays
Dichlorvos (0.25%)	Abraham and Kurian (1975); Abraham *et al.* (1975)	curative-stem infusion
Dimethoate (O,O-Dimethyl S-(N-Methylcarbamoylmethyl Dithiophosphate)	Azam and Razfi (2001)	
Diofenolan	Ghoneim *et al.* (2007)	
Dursban (chlorpyrifos, 3 ml/1 liter)	Abbas (2013)	
Endosulfan (1,2,3,4,7,7-Hexachlorobicyclo (2.2.1)Hepten-5,6-Bioxymethylenesulfite)	Abraham *et al.* (1998)	
Fenthion (0.2%)	Lakshmanan *et al.* (1972) (as cited in Faleiro (2006a)); Rao *et al.* (1973)	
Garlic oil (Allium sativum)	Murthy and Amonkar (1974)	
Imidacloprid (1-((6-chloro-3-pyridinyl)methyl)-4,5-dihydro-Nnitro-1H-imidazol-2-amine)	Cabello *et al.* (1997); Dembilio *et al.* (2010b); Kaakeh (2006)	curative-soil application
Jojoba oil (Joj)	Bream *et al.* (2001)	
Lufenuron	Ghoneim *et al.* (2007)	
Malathion (Dicarboethoxyethyl O,O-Dimethyl Phosphorodithioate)	Abraham and Kurian (1975); Abraham *et al.* (1975)	Lethal to palm
Marshal (Carbosulfan)	Azam and Razfi (2001); Mathen and Kurian (1962)	

Table (22): Continue..

Chemical product	Reference	Note
Methyl demeton	Abraham *et al.* (1975); Abraham and Kurian (1975); Azam and Razfi (2001); El-Ezaby (1997); Lakshmanan *et al.* (1972) (as cited in Faleiro(2006a)); Rao *et al.* (1973)	
Methidathion (O,O-dimethyl-s-(2-methoxy-1,3,4-thiadiazol-5(4H)-onyl-(4)-methyl)phosphorodithioate)	Ferry and Gómez (2002)	
Methyl bromide (CH3Br)	Oj (1991) (as cited in Liacer and Jacas 2010)	Forbidden Liacer and jacas (2010)
Monocrotophos	Muthuraman (1984)	
Phosphamidon	Abraham *et al.* (1975)	
Phosphine (PH3)	Liacer and jacas (2010); Oj (1991)(as cited in Liacer and Jacas 2010)	
Phostoxin: aluminium phosphide	Lakshmanan *et al.* (1972) (as cited in Faleiro (2006a)); Rao *et al.* (1973)	
Pirimiphos-ethyl	Mathen and Kurian (1962)	
Propoxur (arprocarb)	Abraham *et al.* (1975)	
Pyriproxyfen	Liacer *et al.* (2010)	No effect on RPW
Pyrocon E: a combination of pyrethrins and piperonyl butoxide	Kurian and Mathen (1971)	
Pyriproxyfen	Liacer *et al.* (2010)	No effect on RPW
Rogodial (unspecified composition)	El-Ezaby (1997); Mathen and Kurian (1962)	
Tar	Abraham and Kurian (1975)	No effect on RPW
Thiamethoxam	Marm (2011) (as cited in Dembilio and Jacas (2012))	

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RED PALM WEEVIL

Red palm weevil (RPW) is an invasive species that attacks several palm species (Arecaceae) causing destructive economic damages. It is originated from Southeast Asia
and Melanesia, due to the commercial exchanges of the offshoots among and within different countries, RPW is introduced to other regions. It was introduced to the Middle East in the mid 1980's it is recorded in different localities belonging to Africa, Asia, Caribbean, Europe and the Oceania.
In order to achieve the RPW management objectives, various detection, prevention and treatment methods are tested and /or applied against RPW. Among them there are multi
purpose methods that can be used for the three purposes. Actually, using one method will not give the desired result accordingly, all tested methods should be combined in an integrated pest management strategy (IPM) for best results.

This book serves as a review of literature book that considers the state and progress of the fundamental and applied research on RPW. It addresses large audience such as: lecturers, undergraduate and graduate students, researchers and anyone who is interested
to know about RPW.

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