International Journal of Tropical Insect Science Vol. 26, No. 3, pp. 135–154, 2006 DOI: 10.1079/IJT2006113

Review Article

A review of the issues and management of the red palm weevil *Rhynchophorus ferrugineus* (Coleoptera: Rhynchophoridae) in coconut and date palm during the last one hundred years

J.R. Faleiro*

Plant Protection Laboratory, ICAR Research Complex for Goa, Ela, Old Goa 403 402, India

(Accepted 12 June 2006)

Abstract. The red palm weevil (RPW) *Rhynchophorus ferrugineus* (Olivier), a concealed tissue borer, is a lethal pest of palms and is reported to attack 17 palm species worldwide. Although the weevil was first reported on coconut *Cocos nucifera* from South Asia, during the last two decades it has gained a foothold on date palm *Phoenix dactylifera* in several Middle Eastern countries from where it has moved to Africa and Europe, mainly due to the movement of infested planting material. In the Mediterranean region, RPW also severely damages *Phoenix canariensis.* Currently, the pest is reported in *c.* 15% of the coconut-growing countries and in nearly 50% of the date palm-growing countries. Infested palms, if not detected early and treated, often die. However, palms in the early stages of attack respond to chemical treatment with insecticide. RPW has been managed in several countries employing an integrated pest management (IPM) strategy including the use of food-baited pheromone traps. Early detection of infestation in the field is important for the success of any RPW-IPM programme. Ideally, movement of planting material from infested plantations within the country and also from one country to another needs to be stopped. Wherever this is not possible, it is essential to implement strict pre- and post-entry quarantine regimes, wherein only pest-free and certified planting material can be transported. The existing pheromone-based IPM programme can be strengthened by intensifying the search for effective natural enemies, coupled with the introduction of resistance in palms to RPW. This article reviews the work done during the last 100 years on various aspects of RPW viz. life history, damage and symptoms of attack, seasonal activity, spatial distribution, host range, IPM and its main components, including trapping adult weevils and chemical control, besides biological control, host plant resistance and male sterile technique.

Key words: *Rhynchophorus ferrugineus*, date palm, coconut, review, management

*Email: jrfaleiro@yahoo.co.in

Résumé. Le charançon rouge du palmier (RPW) *Rhynchophorus ferrugineus* (Olivier), un foreur des troncs, est un ravageur mortel des palmiers, signalé sur 17 espèces de palmiers à travers le monde. Bien que signalé pour la première fois sur le cocotier *Cocos nucifera* en Asie du Sud, au cours des deux dernières décades, il s'est établi sur le palmier dattier *Phoenix dactylifera* dans plusieurs pays du Moyen-Orient d'où il s'est propagé en Afrique et en Europe, du fait d'échanges de matériel contaminé. En région méditerranéenne, RPW cause également des dégâts importants à *Phoenix canariensis*. Actuellement, il est signalé dans 15% des surfaces cultivées en cocotiers et près de 50% des surfaces cultivées en palmier dattier. Si les palmiers infestés ne sont pas détectés précocement et traités, ils meurent. Toutefois, les arbres infestés, traités précocement, répondent bien aux insecticides. La lutte intégrée contre le charançon a été pratiquée dans plusieurs pays à l'aide notamment de pièges à phéromones. Toutefois, pour être efficace, ce type de lutte nécessite un dépistage précoce de l'infestation. Dans l'absolu, il faudrait arrêter le transport des jeunes plants à partir des régions infestées et d'un pays à l'autre. Quand cela apparaît impossible, il faudrait imposer une quarantaine avant et après le transport et seul du matériel contrôlé pourra être transporté. Les programmes actuels de lutte intégrée par piégeage phéromonal pourront être renforcés par le recours à des ennemis naturels efficaces couplé à l'utilisation de palmiers résistants au charançon. Cet article fait le point des travaux réalisés au cours des 100 dernières années sur RPW, dans les domaines de la biologie, des dégâts, de l'écologie (cycle saisonnier, distribution spatiale, spectre alimentaire) et de la lutte intégrée (piégeage des adultes, lutte chimique, lutte biologique, lutte variétale et lutte autocide).

Mots clés: *Rhynchophorus ferrugineus*, palmier dattier, cocotier, article de synthèse, gestion

Introduction

The aboriginal home of the red palm weevil (RPW) *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Rhynchophoridae) is South and Southeast Asia, where it is a key pest of coconut *Cocos nucifera* (Lefroy, 1906; Brand, 1917; Viado and Bigornia, 1949; Nirula, 1956a,b). Although Buxton (1920) reported this pest on date palm *Phoenix dactylifera* from Mesopotamia (Iraq), it was only during the mid 1980s that RPW attained a major pest status on date palm, in the Middle Eastern region (Abraham *et al.*, 1998). Subsequently, the weevil moved from North Africa into Europe, where it was reported for the first time in the South of Spain (Cox, 1993; Barranco *et al.*, 1995).

Recent reports suggest that RPW has gained entry into Australia (www.ento.csiro.au/index.html). The RPW spread has been rapid in date palm-growing countries during the past two decades and it has established itself in *c.* 50% of these countries, while the pest is reported from only 15% of the coconut-growing countries (Faleiro, 2006).

The agroclimatic conditions prevailing in the Middle East and other date palm-growing countries, along with the unique morphology of the crop, coupled with intensive modern date palm-farming practices have offered the pest an ideal ecological niche. In addition, huge shipments of planting material from one country to another have contributed to the rapid spread of the pest in the Middle East, Africa and Europe (Abraham *et al.*, 1998). Currently, RPW is rapidly spreading in the Mediterranean basin through *P. dactylifera* and *Phoenix canariensis* date palms. At a global level, only the American continent is apparently free of the pest. The recently concluded first International Workshop on RPW in Valencia, Spain during November 2005 highlighted the magnitude of the problem and the urgency of combating the pest (www.redpalmweevil.com).

This article reviews the work done during the last 100 years (since 1906) on the life history, damage symptoms, seasonal activity, distribution, host range and management of RPW. It also gives an account of the adult population trapping using food baits and pheromone lures, and chemical control, biological control, host plant resistance and male sterile technique.

Life history and rearing

The RPW life history has been studied in many countries including India, Indonesia, Myanmar, Philippines, Iran and Spain (Esteban-Duran *et al.*, 1998; Murphy and Briscoe, 1999). The female oviposits in holes made with its rostrum (Nirula, 1956a). A single female lays 58–531 eggs, which incubate for 1–6 days, before hatching into whitish-yellow larvae (grubs), which live for 25–105 days (Wattanapongsiri, 1966; Avand Faghih, 1996; Abraham *et al.*, 2002). The grubs chew the plant tissue and move towards the interior of the palm, leaving behind chewed-up frass (plant fibres), which have a typical fermented odour. Frequently, the frass protrudes through the holes on the infested stem/petiole. Viado and Bigornia (1949) reported nine larval instars for RPW, while Nilura (1956a) reported only three. Further, Jaya *et al.* (2000) reported seven instars when RPW was reared in the laboratory, on sugarcane. The completely developed grubs pupate in a cocoon (*c.* 80 x 35 mm) made from chewed fibres. The pupal developmental period ranges from 11 to 45 days.

The life cycle of the pest may vary from just 45 days as reported from the Philippines, to 139 days as recorded from Spain (Esteban-Duran *et al.*, 1998; Murphy and Briscoe, 1999). According to Rahalkar *et al.* (1972), the environmental changes do not have a marked influence on the growth and development of the weevil. However, Ramachandran (1991, 1998) revealed variations in morphology and habit of RPW samples collected from different parts of India and suggested that fecundity and sex ratio may influence F_1 and F_2 progeny. DNA fingerprints of three morphologically different forms of RPW collected from Egyptian date plantations indicated major genetic variations in the three forms (Salama and Saker, 2002). This could have major implications for the control strategies, particularly with regard to the response of the adults to semiochemicals.

Several overlapping generations comprised of different stages of the insect may be seen inside an infested palm. Rahalkar *et al.* (1972) reported 3–4 generations per year. Nirula (1956a) estimated the RPW potential rate of multiplication to be high and reported that a single female may give rise to more than five million weevils in four generations, within 14 months. However, based on subsequent reports (Rahalkar *et al.*, 1972; Avand Faghih, 1996; Esteban-Duran *et al.*, 1998; Cabello, 2006), this estimate on the multiplication rate is unusually high. Salama *et al.* (2002) estimated that RPW had 21 generations annually in Egypt. The high rate of multiplication may be attributed to the continuous egg-laying throughout the year, with some periods being more intense than others. Even if a fraction of this population survives in the field, it would pose a substantial threat to the preferred host palm species. Studies on the bioecology of RPW to understand how this insect easily adapts to the arid-desert agroecosystem of the Middle East from its warm, humid and tropical home in South and Southeast Asia could be useful in refining the management options against the pest.

Laboratory mass rearing of RPW is essential to test and improve the control strategies to be adopted against this pest. Rahalkar *et al.* (1972) first successfully reared the weevil on sugarcane stem, while Rananavare *et al.* (1975) standardized a mass rearing method for this pest from which over 50 laboratory-reared generations were obtained. Subsequently, Rahalker *et al.* (1978) developed an artificial diet for rearing the weevil using sugarcane bagasse, fresh coconut cake, brewer's yeast, sugarcane, potassium hydroxide, methyl parahydroxyl benzoate and sorbic acid solutions. Further, Salama and Abdel-Razek (2002) reared the insect on a semiartificial diet in Egypt, while El-Sebay *et al.* (2003) developed an artificial diet for RPW consisting of potato, carrot, casein, agar, cereals and vitamins B and D. RPW larvae reared on different diets revealed that α-amylases of *R. ferrugineus* are key enzymes in the pest's development. This finding offers the possibility of new pest control strategies based on the use of enzyme inhibitors (Alarcon *et al.*, 2004).

Damage and symptoms of infestation

RPW is reported to mostly attack young palms, i.e. below the age of 20 years (Nirula, 1956a; Abraham *et al.*, 1998). In general, females lay eggs in wounds, cracks and crevices on the trunk from the collar region near the roots to the base of frond petioles/axils near the crown. In coconut, damage due to the rhinoceros beetle *Oryctes* spp. and the diseases of frond rot and bud rot may predispose the RPW females to oviposit into the palm (Abraham and Kurian, 1975; Abraham *et al.*, 1998).

The newly hatched grubs bore into the surrounding plant tissue. According to Abraham *et al.* (1998), damaged palms exhibit one of the following symptoms depending on the stage of attack: (i) presence of tunnels on the trunk and base of frond petiole, (ii) gnawing sound due to feeding by grubs, (iii) oozing out of thick brown fluid from the tunnels, (iv) appearance of chewed plant tissues (frass) with a typical fermented odour, in and around tunnel openings, (v) fallen empty pupal cases and dead adults around a heavily infested palm and (vi) breaking of the trunk or toppling of the crown in case of severe and prolonged infestation. In date palm, infested offshoots become dry. When infestation is in the coconut crown, wilting or yellowing of inner fronds may occur (Abraham *et al.*, 1966).

In the field, the aforementioned damage symptoms can be perceived either visually or from the sound caused by feeding grubs, or by smelling the typical fermented odour of infested palm tissue.

The success of any RPW-IPM programme lies in the ability of the field staff to detect infested palms at an early stage of attack. The aids for detecting infestation viz. endoscope (Hamad Saad Al-Saad and Mahdi, 2004), and equipment for picking up gnawing sounds made by feeding grubs (Abraham *et al.*, 1966; Soroker *et al.*, 2004) and use of sniffer dogs (Nakash *et al.*, 2000) to detect infested palms could play an important role in enhancing the efficiency of a RPW-IPM programme. The availability of efficient, sensitive, cost-effective and easy-to-handle sound recording devices could be a major step in this direction. In Israel and Egypt, satellite-aided global positioning system is being used to keep track of infestations in the field (Brun *et al.*, 2006; Soroker *et al.*, 2006).

El-Ezaby (1997) categorized RPW infestation in date palm on a scale of 0–5, where 0 represents uninfested palms (showing no stages of the pest or damage symptoms), while 5 indicates advanced stage of attack where an infested palm topples. The high value of the crops involved and the lethal nature of the pest implies immediate action against RPW, which may be initiated either when one infested palm is observed for small holdings or if 1% infestation has been recorded in large plantations (Faleiro, 2006).

Seasonal activity and spatial distribution

Seasonal activity of RPW, as measured through pheromone trap captures, has been reported from the Middle East and South Asia. Vidyasagar *et al.* (2000b) reported a high peak weevil activity from the Al-Qateef region, Saudi Arabia during April–May, followed by a smaller peak during October–November. A similar trend was observed in the Al-Hassa region of Saudi Arabia, with adults emerging during the first peak contributing to the increased infestation levels throughout the summer (Anon., 1998). El-Garhy (1996) studied the seasonal variations and abundance of adult RPW using pheromone traps in date plantations of Egypt and reported high capture rates during April–June, which then slowed down during the cold winter months. A similar trend in peak weevil activity has been reported from Israel (Soroker *et al.*, 2005). El-Sebay (2003) reported two active seasons during a year from Egypt, the first during April and the second during November, but no relationship was observed between seasonal population fluctuations and weather factors. Based on the concept of thermal constant, Salama *et al.* (2002) estimated the lower and upper temperature thresholds, at which the pupae of RPW are killed, to be −2.3 and 45 °C, respectively. Similar results have been reported from Spain (Cabello, 2006).

Under the agroclimatic conditions prevailing in the coastal State of Goa in Western India, RPW was most active between October and November and least active between June and July. Weather as a whole significantly ($R^2 = 0.56$) influenced trap captures of the pest in the State of Goa, with maximum temperature and rainfall having a significant positive and negative correlation, respectively, on the activity of RPW (Faleiro, 2005). Further studies on the diurnal activity of RPW using food-baited pheromone (Ferrugineol) traps from Goa, India showed that RPW adults were most active between midnight and 0600 h, while least activity was recorded between 1800 and 2400 h (midnight) (Faleiro and Satarkar, 2003a). However, reports from Sri Lanka (Gunawardena and Bandarage, 1995) have shown that RPW responds to pheromone-baited traps only between 1800–2000 h and 0600–0800 h.

These differences in the diurnal activity of the RPW as reported from India and Sri Lanka suggest that weather parameters play an important role in determining the activity of this pest, which in turn would influence the management of RPW particularly with regard to the use of food-baited pheromone traps. While Sri Lanka receives rain almost throughout the year, in Goa the monsoon is restricted between June and September. In general, it would be expected that tropical weevils would fly when the relative humidity is highest and temperatures are moderate.

Population dispersion parameters and different dispersion indices for weevil captures, evaluated with pheromone traps in coconut plantations of Goa in India, revealed that RPW population followed an aggregated or a contagious spatial distribution pattern. Owing to the aggregated pattern in RPW population, infestations were reported to occur in clusters in date plantations of Saudi Arabia (Faleiro *et al.*, 2002). These infestation clusters were subjected to intensive management, especially checking of palms to locate new infestations and preventive insecticide applications (Anon., 1998). The RPW spatial distribution should therefore be an important factor in decision making for RPW-IPM programmes.

Host range and IPM

Nirula (1956a) reported RPW on four species of palms and this number increased to 12 when Lever (1969) reviewed the host range of the pest. Subsequently, Esteban-Duran *et al.* (1998) reported RPW on 17 palm species, viz. *Areca catechu*, *Arenga pinnata*, *Borassus flabellifer*, *Caryota maxima*, *C. cumingii*, *Cocos nucifera*, *Corypha gebanga*, *C. umbraculifera*, *C. elata*, *Elaeis guineensis*, *Metroxylon sagu*, *Oreodoxa regia*, *Phoenix canariensis*, *P. dactylifera*, *P. sylvestris*, *Sabal umbraculifera* and

Washingtonia sp. Among the above palm species, RPW has been reported to cause widespread damage in coconut *C. nucifera* and date palm *P. dactylifera* (Abraham *et al.*, 1998).

Since the mid 1970s, RPW has been successfully managed on coconut in India using an IPM programme (Abraham and Kurian, 1975; Abraham *et al.*, 1989). The major components of the RPW-IPM programme in coconut are monitoring, palm and field sanitation, trapping of adults using food baits, preventive chemical treatments of wounds, treatment of palms infected with bud rot disease or infested with *Oryctes* to prevent attraction of RPW adults, filling frond axils of young palms with a mixture of insecticide and sand, curative treatment of infested palms in the early stages of attack, eradicating severely infested palms, cutting fronds if required at a distance of 1 m from the frond base, and educating and training farmers and agricultural officers.

Abraham *et al.* (1989) reduced infestation levels from 6.86 to almost 0% by adopting the above IPM package in coconut plantations of Kerala, India. With the synthesis and availability of the ferruginol-based pheromone lure for RPW, the above IPM programme was accordingly modified to incorporate pheromone traps and it was successfully used to combat the pest in date palm (Abraham *et al.*, 1998). The IPM package included monitoring by periodic field surveys to detect infestations and also through pheromone traps (monitors), adult mass trapping in endemic pockets, treatment of hidden sites including neglected and closed gardens, crop maintenance and field sanitation, preventive and curative chemical treatments, eradication of severely infested palms, implementation of quarantine measures and training and education. Reports from Saudi Arabia suggest that RPW adults are able to use moist soil as temporary harbourage and also that flood irrigation increases infestation in date palm, thus outlining the role of irrigation in the management of RPW (Aldryhim and Khalil, 2003; Aldryhim and Al-Bukiri, 2003). Work done on the major RPW-IPM components, viz. trapping of adults, chemical control, biological control, host-plant resistance and male sterile technique are reviewed later.

Major RPW-IPM components

Food traps

Henry (1917) first suggested that fermenting kitul palm *Caryota urens* (Arecaceae) wood might be effective in trapping RPW adults. Subsequently, Hagley (1965) reported that a mixture of malt extract and iso-amyl acetate is a good attractant to trap *Rhynchophorus palmarum* (Linnaeus) weevils. This mixture was also found to attract adults of RPW in India. Maharaj (1973) reported that metal traps filled with coconut petioles were effective in collecting *R. palmarum*. However, split coconut logs smeared with fresh toddy were found to be more effective in trapping RPW in India (Abraham and Kurian, 1975). Further work done in India showed that out of the 16 food attractant combinations tested in the field, coconut logs treated with coconut toddy + yeast + acetic acid, attracted the highest number of RPW adults (Kurian *et al.*, 1984).

Pheromone traps

Chemical synthesis

Rochat *et al.* (1991) identified the RPW male-produced aggregation pheromone 'rhynchophorol' for *R. palmarum* as (2E)-6-methyl-2-hepten-4-ol. Subsequently, Hallett *et al.* (1993a) identified and synthesized the 'ferrugineol' (4-methyl-5-nonanol) by another male-produced aggregation pheromone. From that time, the pheromone technology has been widely used to manage both *R. palmarum* in oil palm and *R. ferrugineus* on coconut and date palm.

The Sri Lankan researchers, while studying the electroantennogram (EAG) response of male and female adults to 16 terpenes, reported that *R. ferrugineus* was sensitive to the size and the position of oxygen function, degree of unsaturation and degree of olefinic bonds in the molecules (Gunawardena, 1994). Further, workers from the same laboratory reported the synthesis of ferrugineol by using Grignard reaction with butyl magnesium bromide and 2-methyl-1-pentanal. The activity of ferrugineol could be enhanced by combining it with n-pentanol, which is a major constituent of coconut sap, while decanol elicited the lowest EAG response (Gunawardena and Bandarage, 1995).

Electrophysiological and behavioural assays carried out through EAG studies for host (coconut), alternate host and non-host plants revealed that distillates from host plants were more attractive to *R. ferrugineus* compared to alternate and non-host plants (Gunawardena and Swarnakanthi, 1995). Although, the RPW pheromone is reported to be one component (4-methyl-5-nonanol) (Hallett *et al.*, 1993a), experiments conducted in Saudi Arabia showed that addition of the second component (4-methyl-5-nonanone) in small amounts increased capture rates by nearly 65% (Abozuhairah *et al.*, 1996).

Perez *et al.* (1996) suggested a species synonymy for *R. ferrugineus* and *Rhynchophorus vulneratus* (Panzer), since 4-methyl-5-nonanol was produced by both the species. Later, Hallett *et al.* (2004), based on morphological, molecular-genetic and breeding data, proposed that *R. ferrugineus* and *R. vulneratus* should be considered as colour morphs of one and the same species, *R. ferrugineus*, and should be put under the common name 'Asian palm weevil'. Experiments conducted in the United Arab Emirates (UAE) and Egypt during 1997 showed that RPW captures were significantly increased (2–3 times) when ethyl acetate was added to food-baited pheromone traps (Oehlschlager, 1998; El-Sebay, 2003). A recent report from Oman has also come to the same conclusions (Abdallah and Al-Khatri, 2005). It is worth mentioning that ethyl acetate is not a substitute for food baits, but it should be added to food in RPW pheromone traps to enhance weevil captures. Studies on the trap design and protocols for trapping RPW using food-baited pheromone traps are presented later.

Trap design

Owing to their operational ease in servicing (food bait replacement and insecticide renewal) and also trapping efficiency, bucket traps have been widely used to catch *R. palmarum* (Oehlschager *et al.*, 1993). For RPW, inverted bucket traps with windows were initially tried in Saudi Arabia in early 1994. This type of trap, besides losing moisture fast (Oehlschager, 2006), was not easy to service, as it was difficult to untie the plastic plate attached to the bottom of the trap, making servicing tedious. This led to the fabrication and use of upright bucket traps with windows, in Saudi Arabia (Anon, 1998). In addition, upright bucket traps with a rough outer surface/jute sack wrapping, captured more weevils in both date and coconut plantations of Saudi Arabia and India (Abozuhairah *et al.*, 1996; Faleiro *et al.*, 1998; Ajlan and Abdulsalam, 2000). In the UAE, specially fabricated plastic traps with a rough exterior surface have now been designed. Although trap colours do not significantly influence weevil captures (Faleiro, 2005), Hallett *et al.* (1999) recorded higher weevil captures in black bucket traps compared to white traps, while Ajlan and Abdulsalam (2000) captured more weevils in green reusable bucket traps, compared to white and yellow ones.

The upright model of the pheromone trap consists of a polyethylene bucket with four ($1.5 \times 5\,cm^2$) windows cut equidistantly below the upper rim of the bucket. The trap is baited with pheromone and the ethyl acetate lures which are hung from inside the lid of the bucket with a piece of wire. The trap also contains 200 g kairomone-releasing food bait (e.g. dates, coconut petioles and sugarcane) mixed in 1 l of insecticide (0.05% Carbofuran 3G™) solution (Anon., 1998; Oehlschlager, 1998).

Food baits

Host plant and insect-produced chemicals generate synergy for attraction, especially in the order Coleoptera (Borden, 1985). Sugarcane when used with rhynchophorol attracted significantly more adults of *R. palmarum* in oil palm plantations of Costa Rica than sugarcane or rhynchophorol alone (Oehlschlager *et al.*, 1993). The palm volatiles released from the food bait act synergistically with ferrugineol released from the pheromone dispenser to attract RPW adults into the traps (Hallett *et al.*, 1999).

Several workers (Faleiro and Chellapan, 1999; Hallett *et al.*, 1999; Nair *et al.*, 2000) have emphasized the use of food baits in RPW pheromone traps to sustain weevil captures. Testing of different kairomone-releasing food baits in India, indicated that dried dates (*khajur*), once used in the pheromone traps, gave the highest captures of RPW, which was at par with sugarcane and significantly superior to the coconut petiole. However, coconut petiole is the most economically and easily available food bait in countries where coconut is grown and it is therefore recommended in these countries (Faleiro and Satarkar, 2005). Nair *et al.* (2000) found that plantains and sugarcane were equally effective and superior to other food baits tested. Muthiah *et al.* (2005) reported that sugarcane molasses attracted a significantly higher number of weevils followed by tender coconut water.

In the Middle East, the use of dates as food bait in RPW pheromone traps is a common practice (Oehlschlager, 2006). Date palm stem tissue was used in mass trapping the pest in the Al-Hassa region of Saudi Arabia between 1994 and 1998 (Anon, 1998). Date fronds, when used in RPW pheromone traps recorded the least captures in India as compared to sugarcane and coconut stem tissue, which stood first and second, respectively (Muralidharan *et al.*, 1999).

Food bait quantities (coconut petiole) from 0 to 500 g per trap were tested in coconut plantations in India and showed that 200 g coconut petiole per trap was sufficient to maintain the trapping efficiency. Further, it was observed that weevil captures progressively declined when traps were serviced periodically at 10, 20 and 30 days. However, trapping efficiency was sustained when water in the traps was replenished even if the traps were not serviced beyond 15 days (Faleiro, 2005). This emphasizes the need for using water along with food baits, as baits that go dry may minimize bait–lure synergy and consequently restrict trapping efficiency. In Iran, Rochat (2006) reported the use of food bait (dates) hung to the lid of the bucket along with the synthetic lure above the water in the trap. Thus, good food bait mixed with water will maximize the bait–lure synergy and enhance weevil captures.

Reports from Costa Rica indicate that non-repellent additives (propylene glycol) extend the effective life of the food bait from 2 to 7 weeks without addition of water (Oehlschlager, 2006). In Spain, Gomez and Ferry (2002) monitored RPW with pheromone traps containing moist insecticide treated with synthetic food bait in absorbent plastic cubes. Oehlschlager (2006) reported that the key to good food bait is its high sugar content.

Pheromone lures

Besides the food bait, it is essential to use a synthetic lure (ferruginol) that is efficient in attracting RPW adults. Chem Tica International, Costa Rica was the first to commercially formulate and synthesize pheromone lures (Ferrolure) for RPW, during 1994. Subsequently, Agrisense, UK; Calliope, France; Plant Research International (Pherobank), Netherlands and ISCA Technologies, USA (Faleiro and Satarkar, 2003b) have manufactured ferruginol-based lures. Non-commercial ferruginol formulations have also been synthesized by the Department of Chemistry, University of Kelaniya, Sri Lanka; the Central Plantation Crop Research Institute (CPCRI), Kerala, India; INRA Laboratory, Paris, France and Trece Incorporated, USA.

Over the last 10 years, RPW pheromone lures have been tested for their efficiency in coconut and date plantations. The findings of these trials are summarized in Table 1.

As mentioned previously, ethyl acetate is known to increase attraction of *R. ferrugineus* and has been used, along with pheromone and food bait, in mass trapping of the pest in the Middle East (Oehlschlager, 1998; El-Sebay, 2003, Abdallah and Al-Khatri, 2005). Chem Tica International has now incorporated both the pheromone and ethyl acetate lures into a single lure called Ferrolure + HP (Oehlschlager, 2005). Tripheron has also been reported from India to attract RPW. Field trials from India indicate that Tripheron + was at par with Ferrolure + (Krishnakumar *et al.*, 2004). Recently, Ajlan and Abdulsalam (2005) reported superior weevil captures from Saudi Arabia with the non-commercial formulation 8683 over 8685, manufactured by Trece Incorporated, USA.

The aforementioned pheromone lures are manufactured using various types of dispensers ranging from thermoplastic spatulas, vials, sachets, glass ampoules and plastic cans (Faleiro *et al.*, 2000; Faleiro and Satarkar, 2003b). From an operational point of view, it is desirable to have a

Table 1. Efficacy of ferruginol-based pheromone lures for *Rhynchophorus ferrugineus* in coconut and date plantations

No.	Formulations tested	Country/crop/duration of trial	Superior lure	References
1	Chem Tica International (high release/slow release)	Saudi Arabia date palm 90 days	High release	Faleiro *et al.* (2000)
2	Agrisense (fast release/slow release) Chem Tica International (Ferrolure, Ferrolure +) Calliope	Saudi Arabia date palm 30 days	Ferrolure +	Faleiro *et al.* (2000)
3	Agrisense lures Chem Tica International (Ferrolure improved and Ferrolure +)	India coconut two trials 45 days each	Ferrolure improved	Faleiro and Chellappan (1999)
4	Chem Tica International (Ferrolure +) ISCA Technologies lure CPCRI lure Pherobank lure	India coconut two trials 30 days each	Pherobank 400 mg lure	Faleiro and Satarkar (2003b)
5	CPCRI lure Chem Tica International (Ferrolure +)	India coconut 150 days	Ferrolure +	Faleiro *et al.* (2004)
6	Chem Tica International (Ferrolure +) ISCA Technologies lure	India coconut trial discontinued after lure was exhausted	ISCA technologies	Kalleshwaraswamy *et al.* (2004)
7	Agrisense lures Chem Tica International (Ferrolure +)	India coconut 30 days	Agrisense lures and Ferrolure +	Abraham *et al.* (1999a)

dispenser that can be easily installed in the trap and also one in which the chemical lure can be seen so that exhausted dispensers can be easily replaced with fresh lures. Hallett *et al.* (1999) recommended a release rate of 3 mg ferruginol per day for operational trapping programmes. Faleiro (2005) reported that ferruginol sustained the efficiency of trapping the weevil even at a low dose of 0.48 mg per day.

Few reports exist on the field longevity of RPW pheromone lures. Most of the works on this aspect pertain to the widely used commercial lure (Ferrolure and Ferrolure +) manufactured by Chem Tica International, Costa Rica. Ferrolure is composed of 4-methyl-5-nonanol, while Ferrolure + has 10% of 4-methyl-5-nonanone in addition to 4-methyl-5-nonanol. Studies on field longevity are important, as exhausted lures need to be replaced with new pheromone lures to maintain the trapping efficiency in the field. Faleiro *et al.* (1999) devised an easy scoring technique to identify exhausted pheromone lures (Ferrolure) and recommended that lures with less than 5% of the chemical need to be replaced.

Zada *et al.* (2002) determined the release rate of RPW pheromone from commercial lures by using quantitative GC analysis of secondary alcohol pheromones. Under arid environmental conditions in date plantations of Saudi Arabia, RPW pheromone lures exhausted much faster in summer as compared to winter. It was recommended to set the traps under shade so as to maintain a uniform and sustained release of chemical into the environment. Both Ferrolure and Ferrolure + (700 mg) exhausted in *c.* 12 weeks during summer, while the same lure was effective for 24 weeks during winter, provided traps were set under shade. In traps to be exposed to sunlight, Ferrolure + lasts longer (Faleiro *et al.*, 1999).

Field studies from coconut plantations in India have shown that Ferrolure + and Ferrolure lasted in the field for 150 and 84 days, respectively, as compared to Tripheron, which had field longevity of 100 days (Krishnakumar and Maheswari, 2003a). However, a field longevity of 170 days was reported for Tripheron +, which was superior to Ferrolure, but at par with Ferrolure + (Krishnakumar *et al.*, 2004). The low-cost indigenously produced CPCRI lure (78.5 mg) from India was reported to have a field longevity varying from 3 to 5 months (Mayilvaganan *et al.*, 2003; Faleiro *et al.*, 2004). Further, studies from India have reported field longevity of 18–51 weeks for 400 and 1100 mg ISCA Technologies lures, respectively, and longevity of 15 and 35 weeks for 250 and 800 mg Chem Tica lures, respectively (Kalleshwaraswamy *et al.*, 2004).

Insecticide use in traps

Insecticide solution in the trap kills the captured weevils. Experiments in Costa Rica showed that over 90% weevils (*R. palmarum*) placed in traps without a killing agent, escaped within 24 h (Oehlschlager *et al.*, 1993). Trials from Al-Qateef in Saudi Arabia have shown that repellency of insecticides to RPW decreases as Deltamethrin™ < Carbaryl™ < Chlorpyriphos™ < Actelic™ < Endosulphan™ < Quinalphos™ (Abozuhairah *et al.*, 1996). Studies in coconut showed that Carbofuran™ and Carbaryl™ were suitable for use in RPW pheromone traps to retain and kill trapped weevils (Abraham and Nair, 2001; Faleiro and Satarkar, 2002). Insecticide-free funnel traps have also been reported to be effective in retaining captured weevils (Hallett *et al.*, 1999). In Iran, soap solution was used to retain captured weevils in bucket traps (Rochat, 2006). It is important that the odour of the insecticide/soap used does not mask or counter the synergistic action between the bait and lure.

Trap placement and trapping density

Initial trials from Indonesia and UAE recommend placing of traps on the trunk of palms (Hallett *et al.*, 1993b). Traps placed vertically at different heights of the palm indicated that the highest weevil captures were recorded when the traps were placed at 1.0 m height in coconut plantations of Goa (Faleiro, 2005). In both mass trapping and monitoring programmes, RPW was managed in vast tracts of date plantations in Saudi Arabia between 1994 and 1998, by setting traps at waist height on date palm trunks (Abraham *et al.*, 2000; Vidyasagar *et al.*, 2000b). Rajpakse *et al.*, (1998) hung traps at 1.5 m above ground for mass trapping the pest in Sri Lanka. Under Middle Eastern conditions, traps placed at ground level or partially buried in the ground were more effective (Oehlschlager, 2006). Currently, in RPW-IPM programmes, traps are set at ground level in several countries, including Israel, UAE and Spain. However, traps placed at waist height on tree trunks are convenient to service compared to those set at ground level (Faleiro, 2006).

Oehlschlager (1994) recommended a trap density of 1 trap per ha in mass-trapping programmes. In Saudi Arabia, effective mass trapping of the pest in endemic areas was achieved with 1 trap per 1.5 ha, while in pest-free areas, the pest was effectively monitored using 1 trap per 100 ha (Abraham *et al.*, 2000). In Egypt, 1 trap for 2 ha was found to be the best trap density, which attracted the highest number of weevils (Anon., 2004). Trials conducted on this aspect, in coconut plantations of Goa, recommend mass trapping of the pest at a trap density of 1 trap per ha, with catches being doubled by increasing the density to 2 traps per ha (Faleiro and Satarkar, 2003c). RPW was successfully managed within 2 years on 450 ha date plantations in Israel, by mass-trapping the pest at a high trap density of 10 traps per ha, in infested plantations, while monitoring its activity using 1 trap per 3 ha on 2200 ha (Soroker *et al.*, 2005). The agroecosystem involved and the resources available would influence the decision on trap density to be used.

Status of trapped female weevils

Ferruginol-based pheromone traps for RPW have been reported to capture more females than males (Oehlschlager, 1994; Hallett *et al.*, 1999; Abraham *et al.*, 1999b; Vidyasagar *et al.*, 2000b; Faleiro and Satarkar, 2003a; Soroker *et al.*, 2005). On an average, for every male weevil captured, two females are trapped. This presents an advantage for weevil population management as the pheromones attract more females that would lay eggs, which would hatch into damage-inflicting grubs. Laboratory studies on the reproductive status and age of females trapped in ferruginol-based traps carried out in Saudi Arabia and India have shown that most female adults captured in pheromone traps were young, fertile or gravid (Abraham *et al.*, 2001; Faleiro *et al.*, 2003). Dissection of pheromone-trapped female weevils in India also revealed that most of them were gravid or had initiated egg development (Kalleshwaraswamy *et al.*, 2005). These studies therefore suggest the potential benefits of using food-baited pheromone traps in mass-trapping programmes to curtail the RPW population build-up in the field. The preferential RPW female attraction to bait in the pheromone traps may be due to a number of factors, viz. pressure on females to disperse in search of mates, food resources and oviposition sites. This phenomenon of female-biased attraction to the bait requires further studies (Soroker *et al.*, 2005).

Impact of RPW mass trapping and IPM programmes

Pheromone traps have been incorporated into RPW-IPM programmes and used to successfully monitor and mass trap the pest in several countries. In the Al-Hassa region of Saudi Arabia, mass trapping of RPW, between 1994 and 1998, maintained infestation levels below 1% in the endemic areas of *c.* 4000 ha of date plantations, while also restricting its spread in the relatively pest-free areas (Abraham *et al.*, 2000). Similarly, in the Al-Qateef region of Saudi Arabia, infestation levels were reduced from 7% in 1993 to 3% in 1997 using a RPW-IPM programme in which pheromone trapping played a key role. Weevil captures reduced from four in 1994 to two weevils per trap per week, at the end of 1997 (Vidyasagar *et al.*, 2000a,b).

Mass trapping the pest along with other RPW-IPM tactics for 2 years between 1999 and 2001, on 450 ha of date plantations in Israel, resulted in a significantly decreased number of weevils trapped by the end of 2001. No infestation has been found since 2002 (Soroker *et al.*, 2005). Large-scale studies in UAE have shown that in 2 years, infestations in date palm reduced by *c.* 36% in plantations, where insecticide sprays were used. When spraying was combined with pheromone trapping a 64% reduction in infestation was observed (El-Ezaby *et al.*, 1998). In another study from the UAE, pheromone trapping for 1 year on six different farms not sprayed with insecticides resulted in reduction of infestation by 71% (Oehlschlager, 2006). Implementation of a pheromone-based RPW-IPM programme in the Sultanate of Oman resulted in an eradication of infested date palms, from 24% in 1998 to only 3% in 2003 (Al-Khatri, 2004).

Continuous trapping of RPW over a period of time significantly lowered infestation levels in Sri Lanka coconut plantations (Rajapakse *et al.*, 1998). In India, mass trapping of the pest along with other RPW-IPM components in *c.* 45 ha of scattered coconut gardens, with initial infestation levels of up to 5%, has stopped new infestation after 1 year (Faleiro, 2005). Experiences on oil palm in Costa Rica have shown that *R. palmarum* was reduced by 90% in 2 years of trapping carried out between 1991 and 1993 (Oehlschlager *et al.*, 2002).

Recently, Rochat (2006) has reported increased infestations near RPW pheromone traps in date plantations in Iran. This needs to be investigated further, by looking into the trap design used, bait–lure synergy, etc., as it is the only documented case, where increased infestations in the vicinity of RPW pheromone traps were observed. It would, however, be advisable to protect young palms within a 50–100 m radius around the trap site by periodic insecticide cover sprays, especially when recommended trapping protocols (Hallett, *et al.*, 1999; Faleiro, 2005) are not followed. Information on the sexual and physiological status of the trapped weevils could help better understand the entire mechanism underlying semiochemical trapping in RPW. Further, understanding the behavioural response of the adult weevils to the chemical lure could enhance trapping efficiency of RPW pheromone traps.

In case of *R. cruentatus*, increased sexual stimulation in weevil aggregation is reported to be pheromone- (5-methyl-4-octanol) mediated, where the males were significantly stimulated to mate in the presence of cruentol, a synthetic aggregation pheromone (Vanderbilt *et al.*, 1998). The repellents for *R. palmarum* have been shown to reduce pheromone trap captures by over 50%. These repellents could be used in push–pull strategies for palm weevil management (Oehlschlager, 2005).

Chemical control

Laboratory bioassays

The potency of several insecticides against RPW has been tested in the laboratory through bioassay studies. Mathen and Kurian (1962), recorded 92% mortality in grubs, using 0.5% Endrin™, while 1% Endrin™ resulted in 100% adult mortality. Later, Abraham (1971) found that tar alone did not prevent RPW from laying eggs on palm tissue in the laboratory. However, benzene hexachloride (BHC) or BHC + tar were completely effective. Abraham *et al.* (1975) achieved 100% mortality of RPW larvae in the laboratory on the 7th day with 0.25% Dichlorvos™, 0.5% Methyl demeton™, Phosphamidon™, Arprocarb™, 1% Trichlorphon™ and Malathion™ or 2% Parathion™.

Laboratory trials in Spain with Imidacloprid™ (Confidor™) and Oxamyl™ at 0.1 and 0.84 g/litre of artificial diet, respectively, showed that Imidacloprid™ was effective against all the larval stages of RPW, while Oxamyl™ induced 71.8% mortality in 30-day-old larvae, after 16 days (Cabello *et al.*, 1997). El-Ezaby (1997) obtained high mortality of larvae, pupae and adults in the laboratory with Marshal™, Primicid™ and Rogodial™. Further, Barranco *et al.* (1998) during laboratory assays with insecticides found that more than 0.1 ppm Fipronil™ incorporated in semi artificial diet resulted in 100% mortality in younger larvae. Fipronil™ at more than 0.2 ppm gave 100% mortality in 30-day-old larvae. Abdulsalam *et al.* (2001), while studying the effect of Fipronil™ 50 and 200 Sc on different stages of RPW achieved 100% mortality of larvae and adults, at 25 ppm Fipronil™ after 1 week. Although higher concentrations of Fipronil™ had no effect on egg hatching, it was effective in suppressing adult emergence. Laboratory studies with pyrethroids in Saudi Arabia revealed that Cypermethrin™ was most effective against larvae and adults than Permethrin™, Deltamethrin™ and Fenvalerate™ (Abo-El-Saad *et al.*, 2001). Studies from the same laboratory using organophosphorus insecticides showed that Pirimphos-methyl™ was more potent against adult weevils than Chlorpyriphos™, while Oxydemeton-methyl™ showed greater insecticidal activity against larvae (Ajlan *et al.*, 2000).

An interesting study from India showed that 10% cashew apple extract was as effective as 1% Carbaryl™ in killing larvae of RPW in the laboratory (Krishnakumar and Maheswari, 2003b). Al-Rajhy *et al.* (2005) tested the insecticidal activity of Carbaryl™ and its mixture with piperonylbutoxide against RPW in Saudi Arabia and found that larvae were more susceptible than adults. In addition, the materials tested were more toxic by ingestion than by topical application, and oxidases were found to reduce Carbaryl™ toxicity, while getting inhibited by piperonylbutoxide. Laboratory screening of new insecticides against RPW showed that 0.05% Carbosulphan™ was significantly superior against adult weevils and fifth instar grubs (Beevi *et al.*, 2004).

Preventive treatments

Insecticides have been used in coconut and date palm plantations on a preventive/prophylactic basis by the following methods: (i) protecting wounds (coconut/date palm) with insecticide, (ii) frond axil filling (coconut), (iii) spraying/soaking (coconut/date palm), (iv) dipping offshoots in insecticide for quarantine purpose (date palm) and (v) soil application (date palm).

Brand (1917) recommended covering exposed wounds of coconut trunks with lime mortar to prevent RPW females from egg-laying. Later, Abraham (1971) recommended dressing wounds on coconut palm with BHC + tar to prevent egg-laying. In *P. canariensis*, where the fronds are cut close to the trunk, it is essential to spray the injured and exposed frond base with insecticide immediately after the frond is cut and before the plant tissue dries. This would prevent the wounded frond base close to the trunk from attracting female weevils for egg laying (Faleiro, 2006). Filling frond axils with 5% BHC or Chlordane™ dust has been one of the earliest recommendations of using insecticide to prevent RPW attack (Anon., 1956). Subsequently, Kurian and Mathen (1971) and Abraham *et al.* (1989) suggested filling frond axils of coconut with BHC + sand. Although BHC was previously widely recommended against RPW and other pests, this chlorinated hydrocarbon is banned due to its persistence in the environment.

Periodic soaking/showering of date palms within endemic pockets with insecticide was one of the RPW-IPM components implemented against the pest in date plantations of Saudi Arabia and UAE (Abraham *et al.*, 2000; Vidyasagar *et al.*, 2000a; Oehlschlager, 2005). In Saudi Arabia, soaking/showering of date palms was achieved by using a modified spray lance without a nozzle (Anon., 1998).

Salama and Abd-Elgawad (2003) suggested the stopping of RPW from spreading to secondary foci within Egypt through quarantine and certification programmes and proposed zero tolerance for RPW. This requires sampling every unit in a lot of palms to be transported. Ideally, it would be advisable to ban the movement of planting material from infested to pest-free areas. However, due to regional and international commitments, this is not always possible. To overcome this problem, Faleiro (2006) proposed pre- and post-entry chemical treatments coupled with inspection and certification of planting material that is to be transported/shipped from one country to another.

As a quarantine measure, it has been recommended to dip the base of date palm offshoots in insecticide solution/mud–insecticide mixtures before transporting them for planting (Anon., 1998, 2004). However, insecticide-based quarantine protocols have yet to be standardized for adoption in the field with respect to transport/shipping of planting material, especially date palm.

In Israel, prophylactic measures to prevent weevil attack on offshoots are implemented with insecticide trunk sprays up to 2 m height from May to June twice a month, using either 0.2% Azinphos methyl™, 0.3% Diazinon™ or 0.15% Chlorpyriphos™ (Soroker *et al.*, 2005). Further, recommendations from Israel also suggest an Imidacloprid™ application to soil, i.e. around 5 ml per palm in irrigation water during March–May and again after harvest in September as a prophylactic measure against the pest (Anon., 2004). Sprays of Carbaryl™, Imidacloprid™ and Fipronil™ had the highest efficacy when mixed with summer oil on date palm in Spain (Hernandez-Marante *et al.*, 2003).

Curative treatments

Green (1906) suggested an application of tar and plastering of the wounds on the coconut trunk with cement after removal of infested palm tissue. RPW-infested palms in the early stage of attack have been cured with insecticide treatment by adopting the following methods, viz. (i) trunk injection (coconut/date palm), (ii) root feeding (coconut) and (iii) fumigation (coconut/date palm).

Stem/trunk injection has been recommended by several workers, wherein insecticide solution is either poured into the infested cavities through exit holes/feeding tunnels or through holes artificially drilled into the palm at an angle so as to reach the cavity. Some workers have recommended repeating the injection until the infestation is completely controlled. A summary of work done on this aspect is presented in Table 2. Abdallah and Al-Khatri (2000) achieved successful treatment of RPW-infested date palms by pouring 50 ml insecticide solution (12 ml Formothion™ + 38 ml water) into three holes, viz. at the infestation point and into two other holes drilled 20 cm above and below this point. Highest insect mortality in the field on

Table 2. Reports of stem injection to treat *Rhynchophorus ferrugineus*-infested coconut and date palms

No.	Chemical tested	Crop	Country	Reference
1	Methyl demeton™	Coconut	Sri Lanka	Kirthisinghe (1966)
2	1% Carbaryl isobenzene™, Dimethoate™	Coconut	India	Mathen and Kurian (1967)
3	1% Carbaryl WP™ (20–30 g in water)	Coconut	India	Mathen and Kurian (1970)
4	1% Carbaryl™ or PyroconE™ after plugging holes	Coconut	India	Kurian and Mathen (1971)
5	0.2% Fenthion™, 1% Carbaryl™, (0.2% Methyl demeton™ phytotoxic)	Coconut	India	Lakshmanan *et al.* (1972)
6	0.2% Fenthion™, 1% Carbaryl™	Coconut	India	Subba Rao *et al.* (1973)
7	1% Trichlorphon™	Coconut	India	Abraham *et al.* (1975)
8	1% Gamma BHC (Lindane™), Diazinol™, Dimethoate™, Malathion™	Coconut	Philippines	Abad and Gallego (1978)
9	10 ml Monocrotophos™ or 5 ml Monocrotophos™ + 5 ml Dichlorvos™ per infested palm	Coconut	India	Muthuraman (1984)
10	Monocrotophos™	Coconut	India	Rajmanickam *et al.* (1995)
11	Marshal™, Primicid™ and Rogodial™	Date palm	UAE	El-Ezaby (1997)
12	2% Metasystox™, Trichlorphon™, Supracid™ and Salut™	Date palm	Saudi Arabia	Anon. (1998) and Vidyasagar *et al.* (2000a)
13	Diazinon™, Dimethoate™, Chlorpyriphos™, Carbaryl™, Oxamyl™, Carbosulphan™, Imidacloprid™, Fipronil™ and Methidathion™	Date palm	Spain	Hernandez-Marante *et al.* (2003)
14	Dichlorvos™ and Imidacloprid™ (infusion, 100–150 cc every 3 weeks until infestation disappears)	Date palm	Israel	Anon. (2004)
15	10,000 ppm of Chlorpyriphos™, Diazinon™, Phenthoate™ and Methomyl™	Date palm	Egypt	Anon. (2004)

infested palms was obtained with a combination of trunk injection and spray with the same insecticide (Hernandez-Marante *et al.*, 2003).

Improved stem-injecting systems to facilitate injection of insecticide into coconut palm for RPW control have been reported from India and Sri Lanka by Wickremasuriya (1958) and Ramchandran and Nair (1994).

Reports from India suggest that administering a systemic insecticide through the roots of the infested palms could cure coconut palms infested with RPW. Monocrotophos™ (10 ml) diluted in equal quantity of water and administered through roots of infested palms effectively controls the pest (Ganeswara Rao *et al.*, 1980, 1989). Studies on this aspect from India have shown that feeding roots with 5 ml Monocrotophos™ + 5 ml Dichlorvos™ was successful in treating infested palms (Muthuraman, 1984). This method of treatment has, however, not been popular due to the problem of locating the feeder roots to administer the chemical.

In addition to the aforementioned curative control methods, fumigating palm cavities/tunnels bored by grubs, with aluminium phosphide tablets has been used to cure RPW-infested coconut and date palm (Lakshmanan *et al.*, 1972; Subba Rao *et al.*, 1973; Muthuraman, 1984; Vidyasagar *et al.*, 2000a). In this method, 1–2 aluminium phosphide tablets are inserted into the infested palm cavity/tunnel, which release phosphine gas that kills all the stages of the pest. Such treated cavities/tunnels have to be completely sealed to prevent gas from escaping. The phosphine gas may often be restricted from spreading within the tunnels due to the frass (plant tissues) generated by the feeding larvae.

Biological control

Murphy and Briscoe (1999) reviewed the prospects for biological control as a component of the RPW-IPM programme. Their review highlighted gaps in the knowledge in the extent and types of natural enemies with regard to *Rhynchophorus* spp. The authors emphasized the need to conduct extensive surveys with a priority of finding natural enemies from the region of geographical origin of different *Rhynchophorus* spp., including RPW, and from those areas into which RPW has migrated. A wide range of RPW natural enemies, viz. insects, bacteria, fungi, viruses, yeasts, entomopathogenic nematodes (EPN) and birds have been reported from several countries. Laboratory studies to evaluate natural enemies against RPW are presented in Table 3.

In the field, entomopathogenic nematodes have been reported to cause mortality to larvae and adults of RPW in date palm from the Middle East. Steinernematid and heterorhabditid nematodes were isolated from weevils collected from the field in Egypt. The treatment of soil around palms with 8×10^6 infective juveniles/palm led to 33–87% adult mortality, while spraying the palm trunk with the same nematode suspension resulted in only 8–13% adult mortality (Abbas *et al.*, 2000). Further, Abbas *et al.* (2001b) recorded 67% mortality of larvae in the field, but the pest could not be completely controlled due to hot weather conditions, the tunnelling nature of RPW larvae and large amounts of frass at the infested point of the palm trunk. Monzer and El-Rahman (2003) concluded that ethanol, acetic acid and ethyl acetate generated by RPW-infested palm tissue inhibit the activity of the entomopathogenic nematodes *Heterorhabditis indica*. Salama and Abd-Elgawad (2001) isolated *Heterorhabditis* spp. from five sites in Egypt. However, only two out of the five isolated nematode strains survived a 24-h exposure in RPW-infested palm tissue, which had had a low viability of only 14–19%.

Antidesiccants were reported to improve the efficacy of entomopathogenic nematodes isolated from date plantations in the Eastern province of Saudi Arabia (Hanounik *et al.*, 2000). The Saudi Arabian strain of *H. indica* induced 60 and 46% larval and adult mortality, respectively, when the nematode was applied into the soil (Saleh and Alheji, 2003). Monzer (2004) suggested the use of an agarose assay as a simple and rapid laboratory test for measuring chemo-attraction of nematodes to host diffusates and host recognition as a predictive screening tool for field testing of new *Heterorhabditis* isolates. Hanounik (1998) reviewed the potential of using steinernematid and heterorhabditid nematodes as biological control agents for RPW. However, attempts to control the pest in the field with entomopathogenic nematodes have not been successful, probably due to the reasons cited earlier. Abraham *et al.* (2002), while reviewing the management technologies for RPW, highlighted the concealed nature of the pest as the main limiting factor for the successful implementation of biological control against it.

Alfazariy (2004) has reported the infectivity of *Bacillus thuringiensis* subspecies *kurstaki (Btk)* and a polyhedrosis virus to larvae of RPW. These pathogens were isolated from the field in Egypt and stored for 4 years as air-dried smears on glass slides, before being tested.

Besides entomopathogenic nematodes reported to cause RPW mortality in the field, Krishnakumar and Sudha (2002) noticed that the Indian tree pie bird *Dendrocitta vagabunda parvula* preys on RPW adults.

Table 3. Laboratory evaluation of natural enemies against *Rhynchophorus ferrugineus*

No.	Biocontrol agent	RPW stage attacked	Country	Reference
1	Bacteria—*Pseudomonas aeruginosa*	Larvae	India	Banerjee and Dangar (1995)
2	Bacteria—*Bacillus* sp., *Serratia* sp. and coryneform group	Larvae and adults	India	Dangar and Banerjee (1993)
3	Bacteria—*Bacillus sphaericus, B. megaterium* and *B. laterosporus*	Larvae	Egypt	Salama *et al.* (2004)
4	Bacteria—*Bacillus thuringiensis, B. sphaericus*	Larvae and adults	Egypt	Alfazariy *et al.* (2003) and Alfazariy (2004)
5	Yeast (isolated from haemolymph)	Larvae and adults	India/Egypt	Dangar (1997) and Salama *et al.* (2004)
6	Virus—cytoplasmic polyhedrosis Virus	All stages	India/Egypt	Gopinadhan (1993), Gopinadhan *et al.* (1990), Alfazariy *et al.* (2003) and Alfazariy (2004)
7	(EPN)—*Heterorhabditis* spp.	Pupae and adults	Egypt	Shamseldean and Abd-Elgawad (1994)
8	(EPN)—*Steinernema abbasi* and *Heterorhabditis indicus* with antidesiccants	Larvae and adults	UAE, Egypt	Abbas *et al.* (2000, 2001a,b)
9	(EPN)—*Teratorhabditis palmarum, Steinernema* sp., *H. indica*	Larvae, pupae and adults	India	Sosamma and Rasmi (2002)
10	(EPN)—*H. indica, Steinernema* sp. and *S. glaseri*	Larvae and adults	India	Banu *et al.* (2003)
11	(EPN)—*H. indica* (Saudi Arabian strain)	Larvae and adults	Saudi Arabia	Saleh and Alheji (2003)
12	(EPN) —*Rhabditis* sp., *H. indica*	Larvae	India	Banu and Rajendran (2002, 2003)
13	Fungi—*Beauveria bassiana* and *Metarhizium anisopliae*	Pupae and adults	Iran	Ghazavi and Avand-Faghih (2002)
14	Fungi—*Beauveria* sp.	Adults	India	Shaju *et al.* (2003)
15	Fly—*Sarcophaga fuscicauda*	Adults	India	Venkatasubbaiyer (1940)
16	Wasp—*Scolia erratica*	Larval parasite		Burkill (1917)

Host plant resistance

Varying levels of damage due to RPW have been reported in different palm species, even within cultivars of the same species. Barranco *et al.* (2002) have reported certain palm species to be resistant to RPW in Spain. Reports from Iran suggest that RPW could not complete its life cycle on the wild palm *Nannorrhops ritchiana*, while the Mazafati variety of date palm was the most preferred host for RPW. Farazmand (2002) also reported that sugar in date palm varieties enhanced growth and daily oviposition, but reduced mortality of RPW, while calcium was found to inhibit the growth of RPW.

Among the coconut varieties, 'Malayan yellow dwarf' was least preferred for egg laying by RPW, while maximum number of eggs were laid in 'Chowghat green dwarf' (Faleiro and Rangnekar, 2001).

Thus, it is highly possible to induce host plant resistance to RPW in both date palm and coconut through classical plant breeding. Additionally, plant-signalling hormones, such as methyl salicylate and methyl jasmoate, known to induce resistance in a wide variety of plants, have not been investigated in date palm.

Finally, genetic engineering offers the possibility of producing Bt endotoxins in palms that could help in managing this problematical pest through host plant resistance. This IPM component must therefore be pursued as a long-term IPM option in the fight against RPW.

Male sterile technique

For the first time, Rahalkar *et al.* (1973) evaluated the feasibility of using the sterile insect technique against RPW. Irradiation of male weevils with a dose of 1.5 Krad 1–2 days after emergence from cocoons induced sterility to the extent of 90%. During 1974, sterile male weevils were released in large-scale field trials in 400 ha coconut plantations of Kerala, India, comprising nearly 20,000 young palms with a 6% RPW damage level. Follow-up studies made with females collected from the experimental areas using coconut log traps showed 70% viability of eggs laid by these weevils (Rahalkar *et al.*, 1977). This was probably due to the fact that the female weevils had already mated with normal males inside the infested palms before flying out for egg laying. Recent studies (Krishnakumar and Maheshwari, 2004) have shown that when normal males replace irradiated males in the laboratory, egg hatching increases from 7 to 67%. In addition, gamma radiation did not have any apparent effect on the F_2 generation (Ramachandran, 1991). The concealed nature of the pest and the opportunity for female weevils to mate with normal males in the field limit the success of this technique.

Conclusion

With the management options currently available against RPW, a pheromone-based strategy offers a sustainable way to tackle this intricate problem in palms through wide area farmer participatory programmes. A complete understanding of the biology of RPW, symptoms of damage and the ecosystem involved is essential to combat this harmful pest. Early detection of infestation in the field is vital for the success of any RPW-IPM programme. Developing, standardizing and implementing plant quarantine protocols are essential to check the movement of RPW into new areas within a given ecosystem and also from one ecological habitat to another, besides preventing re-infestation of areas where the pest has already been controlled. Finding effective natural enemies of RPW, coupled with the introduction of HPR as a component of the IPM strategy can go a long way in strengthening the existing pheromone-based RPW-IPM programme.

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