Biological Control of Red Palm Weevil *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae) By the Natural Enemies

Muhammad Sarwar
Department of Entomology, Nuclear Institute for Food & Agriculture (NIFA), Tarnab, Peshawar, Pakistan; E-mail: drmsarwar64@yahoo.com

Abstract

The red palm weevil *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae), is a highly polyphagous and an important insect pest of several palms wherein the two main palm species concerned are *Phoenix dactylifera* and *P. canariensis*. Knowledge of both its natural enemies and defensive mechanisms against predators and microorganisms is important to develop methods for an integrated pest control. Therefore, the purpose of this article is to emphasize the need for urgent and strong prophylactic measures to avoid new catastrophes and for reinforcement of cooperative international research against this pest. The cause of high rate of spread of this pest is primarily through human's intervention by transporting of infested young or adult date palm trees and offshoots from contaminated to uninfected areas. Biological control is the beneficial action of parasites, predators and pathogens in managing of pests and their damage. Biocontrol provided by living organisms collectively called as 'natural enemies', is especially important for reducing the numbers of palm weevil. Use of several potential biological agents and natural enemies such as parasitoids, predators, pathogens and vertebrates for biological control of palm weevil have been identified effective internationally. The treatments with natural enemies against weevil can reduce its populations both by mortality of the primarily infected weevils and through sublethal effects on reproduction and offspring of these adults and those in contact with them**.** However, among pathogens, the best results against palm weevil larvae and adults are given by various entomopathogenic nematodes (*Steinernema* spp., *Heterorhabditis* spp.), and entomopathogenic fungi (*Beauveria bassiana* and *Metarhizium anisopliae*) under field conditions. But, this biotic control is often harder to recognize, less well understood and more difficult to manage. For better results, their use should be frequent and needs to be done under specific conditions that may significantly increase the rate of treatment. However, the conservation, augmentation and classical biological control are tactics for harnessing of natural enemies' benefits against such a challenging pest of highly valuable trees.

Keywords: Red palm weevil, Biological control, Pest Control agent, Natural enemy

1. Introduction

The red palm weevil *Rhynchophorus ferrugineus* Olivier, has become the most important pest of the date palm in the world (Gomez and Ferry, 1999). The red palm weevil is a member of order Coleoptera in family Curculionidae. The male and female adults are large reddish brown beetles about 3 cm long and with a characteristic long curved rostrum, with strong wings, and they are capable of undertaking long flights. Pupation occurs generally outside the tree trunk at the base of the palms in a cocoon made of brown dried palm fibers. Several overlapping generations with all life stages can be present within the same palm tree. Generally, the adult weevils present in a palm will not move to another one while they can feed on it. Usually the damage caused by the larvae is visible only long after infection, and by the time the first symptoms of the attack appear, they are so serious that they generally result in the death of the tree. This late detection of the presence of the weevil constitutes a serious problem in the fight against the pest and in any attempt to guarantee pest-free status in adult trees. Despite of research carried out so far, no safe techniques for early detection of the pest have been devised. In most of the countries, the two main palm species concerned are *Phoenix dactylifera* and *P. canariensis*, but red palm weevil can also attack some others ornamental palms (Barranco et al., 1998). The *R. ferrugineus* is a serious pest of coconut palms, observed as major pest of oil palms and sago palm, and causes serious damage on date palms. El-Sabea et al., (2009) estimated the economic loss due to the eradication of severely infested palms between 1 and 5% infestation to range from $5.18 to $25.92 million, respectively, with indirect losses increasing this figure to several fold. The estimated cost of saving the curative treatment of palms in the early stage of attack at 1 and 5% infestation levels ranged from $20.73 to $103.66 million, respectively.

Intensive chemical treatments have been used to protect the *Phoenix* palms and to try to cure affected trees. Despite of the difficulty in operating in the public gardens environment, foliage spraying has been conducted with various insecticides like Fenitrotion, Clorpirifos, Diazinon or Metidation. Preventive treatment of all the palms, even healthy ones, has been repeated once a month outside the season. Insecticides such as carbaril and imidacloprid have been injected several times and in various places all around the stems of palms. Simultaneously, a program of mass trapping using aggregation pheromone and semi-synthetic kairomone has been initiated (Esteban-Durán et al., 1998). But, despite of all these efforts, several thousand *Phoenix* trees have been killed by this pest. Knowledge of both its natural enemies and its defensive mechanisms against predators and microorganisms is important to develop methods for an integrated pest control. Antimicrobial activity of the cuticular surface of adults and larvae, as well as of eggs of this invasive species has been investigated. This activity is tested against the gram-positive bacteria *Bacillus subtilis* (Ehrenberg) Cohn and *Bacillus thuringiensis* Berliner, the gram-negative bacterium *Escherichia coli* Escherich, and the entomopathogenic fungi *Beauveria bassiana* (Balsamo) Vuillemin and *Metarhizium anisopliae* (Metchnikoff) Sorokin. A similar analysis is conducted with the hemolymph of *R. ferrugineus* larvae infected by *Pseudomonas aeruginosa* (Schroter) Migula, *E. coli* and *Staphylococcus aureus* Rosenbach. Polar surface fraction of extracts from adults and large larvae inhibits gram-positive bacteria and the *B. bassiana* growth, but not the growth of *E. coli* and *M. anisopliae*. Similarly, the hemolymph of larvae and the surface extracts of both small larvae and eggs seemed not to show any inhibition. Chemical analyses of the fraction exhibiting antimicrobial activity show the presence of some polar compounds ranging between 1000 and 1500 Dalton. This study improves our knowledge on the biology of *R. ferrugineus* and helps to suggest strategies for the biocontrol of this pest (Giuseppe et al., 2011).

2. Identification of Damage by Red Palm Weevil *Rhynchophorus ferrugineus*

During the early stages of infestation, a brown viscous fluid oozes out from the tunnels in the trunk and base of the frond petiole. This liquid solidifies upon exposure to air and some brown flakes can be seen. Another symptom is the presence of bore holes with chewed up fibers. These fibers give out a very foul characteristic smell of red palm weevil's damage. This is a real confirmation of the presence of fresh damage inside the palm. Other symptoms include yellowing or dried central 'heart' leaves, damage of leaves bases and damaged leaves that are under partial or total slope resembling of an open umbrella. Other evidences for weevil's presence are the cocoons found in damaged leaves/ stype/ ground close to the host and the pest itself. Early symptoms can be seen on offshoots of date palm *P. dactylifera* and the Mediterranean fan palm *C. humilis*, where their leaves are chewed or dried (depending on the period of observation). In infested palms, abundant sawdust extruding from larval galleries on the crown or stype (trunk) is visible at the outermost extremity of the galleries. Pupal exuvia on the outside of the stype are also found in May-August (Abbas and Mousa, 2003). Other symptoms/ evidence for palm weevil's presence on palm hosts are perforated or nibbled leaves (nonspecific) (*T. fortunei*, *C. humilis, W. filifera*), gallery holes (axial and transversal) within the stype (*T. fortunei*, *C. humilis*, *W. filifera*) and leaf petioles (*Phoenix* spp., observed when cut), presence of adults during their flight period during May-August, presence of eggs in the palm fibers, abnormal development of auxiliary leaf buds, deformation and abnormal twisting of stypes, abnormal drying up of the palm, especially the core leaves, and heavy larval attack may kill the palm tree (Murphy and Briscoe, 1999).

3. Decision Making for Palm's Treatment

After identifying an infested palm, a treatment decision should be made. Based on the phase or the period (early stage) of the symptoms observed as well as the severity of damage, treatment may be classified into 3 categories (Giblin-Davis et al., 1996):-

I - Early stage damage or slight damage symptoms

The chances that such palms (or offshoots) damaged by the pest shall recover are fairly high.

II - Sloped outermost leaves and galleries on leave's bases

This is the most critical decision to make because it is unknown if the meristem is damaged by the larvae of weevil and in what extent (dendrosurgery may show this). Extension specialists have to be very careful and use their experience to categorize such palms as recoverable or not.

III - Palms with severe infestation

This is the umbrella-like shape, sloped or dried central leaves. There is no cure for it and such palms should be removed carefully and treated in order to kill any living stages of the pest remaining inside the palm parts.

4. Biological Control of Red Palm Weevil *Rhynchophorus ferrugineus*

A great benefit of biological control is its relative safety for human health and the environment, compared to widespread use of broad-spectrum pesticides. Most negative impacts from exotic species have been caused by undesirable organisms contaminating imported goods, by travelers carrying in pest-infested fruit, and from introduced ornamentals that escape cultivation and become weeds. These ill-advised or illegal importations are not part of biological control. Negative impacts have occurred from poorly conceived, quasi-biological control importations of predaceous vertebrates like frogs, mongooses, and certain fish, often conducted by nonscientists.

To avoid these problems, biological control researchers follow government quarantine regulations and work mostly with host-specific natural enemies that pose low risks and can provide great benefits. As a pest comes under biological control, population densities decline for both the pest and the biological control agent because host-specific natural enemies cannot prey or reproduce on other species (Sarwar et al., 2015; Sarwar and Sattar, 2016). Biological control of weevil *R. ferrugineus* has been studied using the strain, UAE-B2 of the entomopathogenic fungus *Beauveria bassiana*. For mass production of dry conidia, a new economically simple medium containing granulated rice is evaluated and used. The culture medium yielded 5.2 mg conidia per cm^2 with a potentiality of 91.7% on adult weevils. Spraying date palm trees with an oil formulation containing 5×10^7 concentrations per ml at a rate of 5 L/ tree caused a mortality of 13.7-19.2% in the adult's population during the three weeks after application with a monthly delayed mortality of 2.3-12.5% in the following per four months. Dusting a date palm tree with 40 g of a powder formulation containing 5% conidia killed 8.9% of adult population during the three weeks after application and caused monthly delayed mortality of 4-5.9% in the following three months (El-Sufty et al., 2007; Van Lenteren, 2012).

5. Types of Natural Enemies of Red Palm Weevil *Rhynchophorus ferrugineus*

Parasites, predators and pathogens are the primary groups used in biological control of insects. Most parasites and pathogens, and many predators, are highly specialized and attack a limited number of closely related pest species. There are few records about the occurrence of natural enemies of *R. ferrugineus*, which might be attributed to the cryptic habitat of the eggs, larvae and pupae which protect them from such natural enemies. Normally, the natural enemies do not play an important part in controlling of *R. ferrugineus*. There are some attempts in the laboratory and field using the predacious black earwig *Chelisoches morio*. However, it does not provide a measurable impact on the control of weevil. Using of pathogens may be rewarding wherein Gopinadhan et al., (1990) reported that a cytoplasmic polyhedrosis virus infected all stages of the weevil and infected late-larval stages resulting in malformed adults and drastic suppression of the host population. Although various species of mites have been reported as parasites of *R. ferrugineus*, and their impact on the population needs to be ascertained. The mites belonging to Macrocheles and Fuscuropoda spp., are found associated with the weevil in the field, however, their role in causing harmful effects to the weevil is not known.

5.1. Parasitoids

A parasite is an organism that lives and feeds in or on a host. Insect parasites can develop on the inside or outside of the host's body. Often only the immature stage of the parasite feeds on the host. The *Scolia erratica* (Hymenoptra: Scoliidae) is reported as an ectoparasitoid of *R. ferrugineus* larvae. However, no biological studies on this parasitoid have been reported. Moura et al., (2006) reported the tachinid *Paratheresia menezesi* as a larval-pupal parasitoid of *R. palmarum* and many individuals of the parasitoid adults emerged from a single pupa. However, attempts are carried out to rear this parasitoid on *R. ferrugineus* in the laboratory, but the results remained unsuccessful. Both pupae and adults of weevil are attacked by an unknown species of parasitic mite which killed the pupae and reduced the longevity of adults. Two mite species, *Hypoaspis* sp., and *Tetrapolypus rhynchophori* (Pymotidae) have been recorded parasitizing the weevil adults; however, the status of such mites as parasitoids is uncertain (Al-Deeb et al., 2012).

5.2. Predators

Predators kill and feed on several to many individual preys during their lifetimes. Many species of amphibians, birds, mammals and reptiles prey extensively on insects. Although the earwigs (Forficulidae: Dermaptera) are considered scavengers, *Chelisoches morio* is a common predator inhabiting the crown of coconuts and the daily average consumption by nymphs and adults of the predator varied between 5.3 and 8.5 *R. ferrugineus* eggs, or 4.2 and 6.7 larvae, respectively. The earwig *Anisolabis maritima* and the anthocorid *Xylocorus galactinus* are recorded as common predators on eggs, larvae and pupae of weevil, and *A. maritima*, showed a higher predatory efficiency. An assay is carried out to evaluate its efficiency as a biocontrol agent against *R. ferrugineus*, on 5 year old date palm offshoots (each caged in a wire cage, 2 × 2 × 2 m). Three pairs of weevil are introduced in each cage in which *A. maritima* is released after 24 h at rates of 5, 10, 15 and 20 pairs per offshoot. One month later, 50% of the offshoots are dissected and the numbers of weevil larvae recorded. The results showed that percentages of infestation in the treated offshoots are 50% (in offshoots with 5 predator couples), 25% (in offshoots with 10, 15 or 20 couples) and 100% (control). A significant reduction in the numbers of weevil larvae is obtained in the offshoots with predators, compared to the control. The larvae found in the five treatments are 12% (in offshoots with 5 or 10 couples), 28% (in offshoots with 15 pairs), 4% (in offshoots with 20 pairs) and 44% (control). The duration of the immature stages of *X. galactinus* is estimated when fed on eggs, 1^{st} instar larvae or pupae of *R. ferrugineus* in the laboratory at 25°C. It is found that the incubation period of the predator egg is 3.6 days (3-4). The nymph (5 instars) lasted 16.5 days (14-19) when fed on 1^{st} instar larvae and 15.5 days (14-17) when feeding on weevil pupae. The average daily consumption of a *X. galactinus* nymph is 1.2-1.8 eggs or 3 larvae and the adult consumed 1.8-2 eggs or 3.6 larvae, daily. Abbas (2010.) obtained *X. galactinus* nymph from a fallen date palm tree, severely infested. However, this species is found associated with larvae of the house fly *Musca domestica*, feeding on the fermented decayed tissues of such a tree. In a food preference test, by exposing larvae of *M. domestica* together with eggs and 1^{st} instar larvae of *R. ferrugineus*, the predator attacked and consumed only larvae of *M. domestica*.

5.3. Pathogens

Natural enemy pathogens are microorganisms including certain bacteria, fungi, nematodes, protozoa, and viruses that can infect and kill the host. Populations of some weevils and other invertebrates are sometimes drastically reduced by naturally occurring pathogens, usually under conditions such as prolonged high humidity or dense pest populations. Banerjee and Dangar (1995) isolated the bacterium *Pseudomonas aeruginosa* from naturally infected adults of *R. ferrugineus*. The bacterium is found to be pathogenic to adults forced to feed on a suspension of bacterial cells and mortality occurred 8 days after ingestion. A highly potent cytoplasmic polyhedrosis virus specific to weevil is also found (Gopinadhan et al., 1990). The virus infected all stages of the insect and laboratory infection of late larval stages resulted in the development of malformed adults. Among fungi, *Beauveria bassiana* is isolated from adults of *R. ferrugineus*. The fungus is found to be highly pathogenic to both larvae and adults in the laboratory (Hanounik et al., 2000; El-Safty et al., 2007).

5.3.1. Viruses

Entomopathogenic viruses belong to 11 families and have been isolated from more than a thousand species and at least 13 different orders of insects. Virus diseases of insects have long been recognized, although only in the last some years there has been increasing interest in the use of these agents to control insect pests (Flexner and Belnavis, 2000). The highly potent cytoplasmic polyhedrosis virus is the only one recorded from palm weevil. After its first record, where it infected all stages of the insects, the virus is detected from dead weevil (El-Minshawy et al., 2005). Infection in the late larval stage resulted in deformed adults and drastically reduced insect's population.

5.3.2. Bacteria

Pathogenic entobacteria mostly belong to the families Bacillaceae, Pseudomonadaceae, Enterobacteriaceae, Streptococcaceae and Micrococaceae. Although many bacteria can infect insects, only members of genera of the order Eubacteriales, Bacillus and Serratia, have been registered for the control of insects. For the genus Rhynchophorus, bacteria have only been isolated from weevil some belonging to Bacillus sp., Serratia sp., and the coryneform group in larvae and adults, while Alfazariy (2004) isolated *Bacillus thuringiensis* Berliner and *Bacillus sphaericus* Meyer and Neide from larvae and adults reported successful for control of weevil in laboratory conditions by infection with *B. thuringiensis* subspecies *kurstaki* isolated from larvae. In contrast, other authors showed a different susceptibility of weevil to *B. thuringiensis* (Manachini et al., 2009). The *Pseudomonas aeruginosa* (Schroeter) is isolated from infected larvae. Laboratory assays demonstrated that this bacterium is pathogenic for weevils when ingested through force-feeding or when insects are forced to wade through a suspension of bacterial cells. Mortality occurred eight days after inoculation and small larvae are more susceptible than larger larvae probably due to lack of antimicrobial cuticular compounds. Salama et al., (2004) isolated three potent spore-forming bacilli from larvae, and the three bacteria belonged to the genus Bacillus and are identified as variants of *B. sphaericus*, *Bacillus megaterium* De Bary and *Bacillus laterosporus* Laubach. Under laboratory conditions, the mortality of larvae ranged between 40% and 60% and the most active culture is that of *B. sphaericus* which produces spherical endospores and crystalline endotoxins, probably responsible for the observed activity against weevil.

5.3.3. Fungi

Many entomogenous fungi are relatively common, often inducing epizootics and thus can be considered a significant factor in the control of insect populations. Most species attacking terrestrial insects belong to the Hyphomycetes and Entomophthorales. Unlike other insect pathogens, fungi usually infect the host by contact, penetrating the insect cuticle (Butt and Goettel, 2000). The host can be infected by: (a) direct treatment, (b) horizontal transmission from infected insects or cadavers to untreated insects, and (c) vertical transmission to subsequent developmental stages via the new generation of spores. The *Beauveria bassiana* (Balsamo) Vuillemin and *Metarhizium anisopliae* (Metchnikoff) Sorokin are two of the most commonly studied species of soil-borne entomopathogenic fungi. Both Beauveria and Metarhizium are cosmopolitan anamorphic genera of facultative necrotrophic arthropod-pathogenic fungi. El-

Sufty et al., (2009) studied the pathogenicity of an indigenous strain of *B. bassiana* isolated from pupae and adults of weevil found that most adults died between the first and second weeks after treatment and that young larvae are more susceptible than old ones; this strain can infect weevil eggs, larvae and adults, the fungus efficiently transmitted the disease to untreated adults of both sexes and reduced fecundity and egg hatching (Dembilio et al., 2010). Sewify et al., (2009) reported interesting results, including a considerable reduction of the palm weevil population, from the use of an indigenous strain of *B. bassiana*, confirming the role of this fungus as a promising biocontrol agent. The *B. bassiana* solid formulation with high weevil's pathogenicity and persistence could be applied both as a preventive treatment and as a curative one for pest control. However, Abdel-Samad et al., (2011) reported that a commercial oil formulation of *B. bassiana* has little effect on weevil, and thus is not a good candidate since it is expensive for field application. Moreover, polar extracts from adults inhibited the germination of *B. bassiana* spores obtained from commercial products. Francardi et al., (2013) showed that *M. anisopliae* isolated from weevil has the highest efficacy against weevil larvae and adults. The Aspergillus sp., Fusarium sp., Metarhizium sp., Penicillium sp., and Trichothecium sp., are isolated from several stages of weevil. One of the last indigenous strains of *B. bassiana* proved useful for the control of small larvae in the laboratory.

5.3.4. Nematodes

The *Praecocilenchus ferruginophorus* (Aphelenchida) is recorded parasitizing *R. ferrugineus* adults and size of nematodes found in the haemocoel ranged from small intrauterine specimens to larger mature parasitic females, suggesting several simultaneous and unsynchronized life cycles in the weevils. Abbas et al., (2001 a) isolated two entomopathogenic nematodes, namely *Steinernema abbasi* and *Heterorhabditis indicus* from *R. ferrugineus* adults. They also showed that 20-100% of the weevil adults are found hosting other non-pathogenic, unidentified nematodes. Nematodes from the families Steinernematidae and Heterorhabditidae are widely regarded as being excellent biological control agents for a number of insect pests in soil and cryptic habitats (Kaya and Gaugler, 1993). They possess many positive attributes including their wide range hosts, safety to vertebrates, plants as well as non-target organisms, ease of in vitro production and application using standard spray equipment. The two families bear mutualistic bacteria in the intestine, belonging to the genera *Xenorhabdus* (Steinernematidae) and *Photorhabdus* (Heterorhabditidae). The free-living, non-feeding 3^{rd} instars (infective juveniles) of these nematodes possess attributes of both insect parasitoids or predators and entomopathogens. Like parasitoids and predators, they have chemo-receptors and are motile; and like pathogens, they are highly virulent, killing their host victims within 24-48 h. Nematodes injection is carried out by making 3-4 artificial tunnels (15-20 cm deep) using an electrical hammer drill with a 20-40 cm long screw, above and around the infested spot, in the palm trunk, where creamy to dark brown sap is noticed (a symptom of weevil's infestation). Nematode suspensions are injected in such tunnels through perforated plastic tubes inserted into such tunnels. After injection, the openings of the tunnels are covered with damp soil to avoid re-infestation. Another method of injecting nematodes in the infested palm trees was tested by Abbas et al., (2000). The leaf-axils are removed from the infested spot on the trunk (showing symptoms of infestation) until reaching the entrance of the larval tunnel. The tunnels are then injected with the nematode suspension containing 5,000 infective juveniles (IJs)/ ml after which the entrances are plugged with damp soil (Shamseldean and Atwa, 2004).

5.3.4.1. Trunk Spraying

A semi-field trial has been conducted by Abbas et al., (2000) to estimate the efficiency of nematodes sprayed against adults of weevil. Sixteen young trees (3-5 years old) have been individually caged by 2 × 2 × 2 m cages made of wooden frame and wire screen. The trunks of 12 trees representing three treatments are sprayed with one l of nematode suspension containing 2 × 106 IJs per tree. The amount of suspension is enough to wet the whole short trunk and sprayed carefully so that it does not reach the soil. Two commercial anti-desiccants, at a rate of 100 ml/ l and at a rate of 2.5 g/ l, are added to the nematode suspension in the first and second treatments, respectively. The last four trees are sprayed with water as control. Ten females and five males of weevil are released in each cage immediately after treatment. The palm trees are inspected daily for 10 days and the dead weevils are transferred to laboratory and kept individually in white-traps for extracting the infective juveniles (IJs) produced by the infected insects. Dead weevils which do not give rise to infective juveniles are dissected to check infection.

5.3.4.2. Soil Treatments

According to field studies and observations Abbas et al., (2001 b), concluded that weevil adults sometimes inhabit soil, probably seeking shade and shelter. This conclusion is based on the subsequent reasons, (i) up to 20-100% of weevil adults collected monthly by pheromone traps are found to be parasitized with unidentified non-pathogenic nematodes, (ii) both *S. abbasi* and *H. indicus* are isolated from weevil adults (iii) young date palm trees (3-10 years old) are found to undergo severe infestation by weevil at or below soil surface, (iv) terrestrial pheromone traps are found to capture 2-3 fold weevil, compared to aerial traps (hung at 1-1.5 m height). On young growing date palms, the weevils take shelter under the splitting bark and lay eggs within the newly emerging roots. Ferry and Gomez (2002) reported that larvae of *R. ferrugineus* could be found in any place within the palm even in the very base of the trunk where the roots emerge. And the emerged adults in this case emerge in the soil.

5.3.5. Protozoa

In the digestive tracts of *R. ferrugineu* there seems to be synergistically degraded by flagellated protozoa. This is the first report on the presence of anaerobic protozoa in the red palm weevil guts. Further research is needed to better understand the ecology of these microbes. Results showed that the isolated protozoa required $NaHCO_3$ and fetal bovine serum for good growth and the presence of yeast extract is stimulatory. Under these conditions, H_2 is a major protozoan fermentation product. Hydrogen production is closely paralleled to cell yields. Flagellated protozoa FP-007 used powdered of cellulose, corncob and cereal leaves as fermentation energy sources, on the other hand chitin showed no growth. The improved growth of the flagellated protozoa FP-007 in vitro should facilitate further studies on the cell biology and biochemistry of these symbiotic, anaerobic protozoa (Ragaei et al., 2009).

6. Insects

Predator and parasitoid insects have been employed in the management of insect pests for centuries since they are natural enemies of various life stages. Natural insect enemies of Rhynchophorus include several species belonging to the orders Dermaptera, Heteroptera, Coleoptera, Diptera and Hymenoptera (Murphy and Briscoe, 1999). Among earwigs, *Chelisoches morio* (Fabricius) is reported as common predator of weevil eggs and larvae in the canopy of coconut plantations, and *Euborellia annulipes* (Lucas) is found in weevil infested palms (Massa and Lo Verde, 2008). A casual occurrence of the predatory bug *Platymeris laevicollis* Distant is found on weevil; this hemipteran, is against *Oryctes rhinoceros* (L.), and seems to prefer weevil. A few predatory coleopterans are associated to Rhynchophorus species. For example, larvae and adults of the rove beetle *Xanthopygus cognatus* Sharp., are egg and larval predators of *R. palmarum*; yet in spite of its feeding preference for the coconut weevil it is a facultative monophagous and can eat other preys when weevils are unavailable. Parasitoids occur in five orders of holometabolous insects, but Diptera and Hymenoptera parasitoids are the best known, including, respectively 20% and 78% of all estimated species. Among Diptera, a few species of Sarcophagidae and Tachinidae exploit Rhynchophorus species as hosts (Murphy and Briscoe, 1999). The *Sarcophaga fuscicauda* Bottcher attack weevil adults and these predaceous and parasitic flies are mostly larviparous, usually feeding on the host larvae and adults. In contrast, Tachinidae larvae are all internal parasitoids, mainly of larvae of Lepidoptera and Coleoptera. The *Billaea menezesi* (Townsend) is a gregarious parasitoid of *R. palmarum* (with an average number of 18 pupae per beetle host) and is recorded in oil palm plantations. The level of parasitism is around 50% and this tachinid fly is observed throughout the year, which is encouraging for its use in integrated pest management. Another tachinid fly, *Billaea rhynchophorae* (Blanchard), is reported as a parasitoid of *R. palmarum*, with a mean parasitism of 40%. Unfortunately, mass rearing of this fly is not possible due to the lack of information about its biological cycle. However, the positioning of a large number of *R. palmarum* cocoons in a close-mesh net cage allowed the collection of parasitoids and their subsequent release (Moura et al., 2006). Laboratory assays performed with another two species of tachinid flies, *Paratheresia claripalpis* Van der Wulp and *Metagonistylum minense* Townsend, revealed no use of *R. palmarum* larvae as hosts after 12 days. Lo Verde and Massa (2007) reported for the first time, the presence of an autochthonous parasitoid of cetonid beetles, *Billaea maritima* (Schiner), on weevil pupae, although no studies have been conducted on this fly. In addition, the generic phorid, *Megaselia scalaris* (Loew), is recently discovered in weevil pupae. Among Hymenoptera, *Scolia erratica* Smith is found as a parasitoid of weevil, but no biological data have been published on this wasp. Further studies are so necessary because scoliid wasps have been successfully used as classic biological control agents since the larvae feed ecto-parasitically on the larvae of Scarabaeidae and less commonly of large Curculionidae (Murphy and Briscoe, 1999). More in-depth studies are necessary to investigate if the autochthonous *Megascolia flavifrons* (Fabricius), commonly found in infested palms, can use weevil larvae as hosts.

7. Mites

Currently, mites are used in various ways for biological control, with an increasing number of species commercially sold throughout the world. They prey on all the development stages, and several species are mass reared commercially for the management of mite, insect, nematode and mollusk pests (as well as noxious weeds) in greenhouses and in field-grown crops (Sarwar, 2013; 2014). These mites belonged to several families such as Acaridae, Anoetidae, Blattisociidae, Diplogyniidae, Macrochelidae and Uropodidae. Some parasitic mites can be associated with Rhynchophorus species, including ectoparasitic podapolid mites (Husband and OConnor, 1999) such as *Rhynchopolipus rhynchophori* (Ewing) on *R. palmarum*, *Rhynchopolipus brachycephalus* Husband and OConnor on *R. phoenicis*, and *Rhynchopolipus swiftae* Husband and OConnor on *R. ferrugineus*. The Hypoaspis sp. and *R. rhynchophori* have been found in association with *R. ferrugineus*, but the status of these species as parasites, remains uncertain. Instead, Abdullah (2009) reported the successful use of *R. rhynchophori* as a biocontrol agent against weevil. Other species (Iphidosoma sp.), reported require more in-depth studies for the correct identification and elucidation of their true relationship with weevil.

8. Vertebrates

In addition to the classic biocontrol agents such as bacteria, fungi and nematodes, some vertebrates (birds and mammals) are reported to eat red palm weevil. The Indian tree pie bird, *Dendrocitta vagabunda parvula* (Whistler and Kinnear), preys on weevil adults. The crow pheasant bird, *Centropus sinensis* Stephens, is an opportunistic feeder, but also reported to take weevil. The Eurasian magpie, *Pica pica* L., is known to eat weevil and several weevil pupae and adults are preyed on by two mammals, *Rattus rattus* and *Apodemus sylvaticus*, in infested palms. However, the role of these fortuitous predators against red palm weevil is very limited and it is more a biological curiosity than one real opportunity of use (Faleiro, 2006; Lo Verde and Massa, 2007; Lo Verde et al., 2008).

9. Conclusion

The use of up to date preventative treatments on healthy palm trees is essential to avoid attack by the red palm weevil. It has been verified that in badly affected areas, healthy species of palms remain pests free when systematic prevention measures are taken and curative treatments have been found effective. The application of the biological treatment using pathogens must also be meticulous, given that it involves the use of living creatures and must be used according to the supplier's instructions. It has been seen that bad practice is fairly common in such treatments during nowadays. In many cases treatments are carried out by gardeners and companies that are neither qualified nor authorized to do so, including official bodies. It is important to stop this bad practice as it produces inefficient treatments and an ensuing loss of credibility in the products used and ability to save specimens. The regular frequency of biological treatments is very important, and it is found that if these initiatives are successful, they will be of great assistance to landscape and orchard managers dealing with such a challenging pest of highly valuable trees. However, the use of integrated treatments using a combination of methods including chemical, biological, mechanical and traps to catch the adults seems to be the most effective method of treatment and prevention. This will not only reduce the pesticide load in the palm orchards, but also help in insect resistance management. Interestingly, further studies are needed to investigate the characterization of the polar substances of adults and larvae and to test which points are responsible for the microbial inhibitory activity.

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