Hellenic Plant Protection Journal **5:** 1-12, 2012

REVIEW ARTICLE

Bio-ecology and integrated management of the red palm weevil, *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae), in the region of Valencia (Spain)

Ó. Dembilio[1]* and J.A. Jacas[2]

Summary The invasive red palm weevil, *Rhynchophorus ferrugineus* Olivier (Coleoptera: Curculionidae), is one of the most destructive pests of palms in the world. It is widely distributed in all continents and has been reported on 26 palm species belonging to 16 different genera. In the Mediterranean basin, *R. ferrugineus* has become the major pest of palms, mainly *Phoenix canariensis* hort. ex Chabaud, an endemic palm to the Canary Islands widely used as ornamental. In this manuscript we summarize the research that the UJI-IVIA Unit has carried out on this pest. The first objective of our work was to determine different bio-ecological parameters of *R. ferrugineus* under natural conditions in a Mediterranean climate. *Washingtonia filifera* is the only palm species included in our studies showing mechanisms of complete resistance against *R. ferrugineus*. Although *Chamaerops humilis* and *Phoenix theophrasti* show antixenotic and antibiotic mechanisms of resistance, respectively, they cannot be considered as resistant against *R. ferrugineus*. Under Mediterranean climate, the preimaginal development of *R. ferrugineus* in *P. canariensis* takes 666.5 DD and the weevil can complete 13 larval instars. Based on the results obtained, less than one generation per year can be expected in areas with a mean annual temperature (MAT) below 15ºC and more than two in those with MAT above 19ºC. Oviposition in *R. ferrugineus* is also strongly affected by temperature. The thresholds for oviposition and egg hatching obtained are very close to MAT registered in most of the northern shore of the Mediterranean basin. Under these circumstances, no new infestations would be expected during most of the winter. The second objective has been to improve chemical and biological control. Both imidacloprid and *Steinernema carpocapsae* in a chitosan formulation are highly effective against *R. ferrugineus* in the field. Different timings and product combinations were studied, and high efficacies were obtained in all cases. An indigenous strain of *Beauveria bassiana,* found naturally infecting pupae of *R. ferrugineus,* resulted highly virulent against all developmental stages of the weevil in the laboratory. Additionally, adults of either sex inoculated with the fungus efficiently transmitted the disease to healthy adults of the opposite sex and this result confirmed the potential of *B. bassiana* as a biological control agent against this pest. These results should help developing an integrated management program against this pest.

Additional Keywords: biological control, chemical control, host range, *Rhynchophorus ferrugineus*

1. Introduction

The invasive red palm weevil, *Rhynchophorus ferrugineus* Olivier (Coleoptera: Curculionidae), is one of the most destructive pests of palms in the world. It is extensively distributed in Oceania, Asia, Africa and Europe and it was found in the Caribbean in 2008 (Aruba and Curaçao) and in California in 2010 (EPPO, 2008; EPPO, 2009; EPPO, 2010). At the present time, this insect has been reported as a pest of 26 palm species belonging to 16 different genera (Malumphy and Moran, 2009). Since its introduction in the Mediter-

[1] Unitat Associada d' Entomologia Agrícola UJI-IVIA; Institut Valencià d' Investigacions Agràries (IVIA); Ctra Montcada-Nàquera km 4.5; E-46113-Montcada (Spain)
[2] Departament de Ciències Agràries i del Medi Natural; Unitat Associada d'Entomologia Agrícola UJI-IVIA; Universitat Jaume I (UJI); Campus del Riu Sec ; E-12071- Castelló de la Plana (Spain)
Corresponding author: dembilio@ivia.es

ranean Basin in 1993, *R. ferrugineus* spread very quickly after 2004, when it was found for the first time in the Region of Valencia (eastern Spain) (Tejedo, 2006). At that time, the Universitat JaumeI-Institut Valencià d'Investigacions Agràries (UJI-IVIA) Unit started a research line aimed at the management of this weevil.

Henceforth we will present a summary of what was already known about the bio-ecology and the management of this pest combined with the new findings that our group achieved.

2. Bio-ecology of *R. ferrugineus*

2.1. Life cycle

Female *R. ferrugineus* weevils lay their eggs singly at the base of the palm fronds in separate holes made with their rostrum. Neonate larvae bore into the palm core making tunnels and feeding on its inner contents. As larvae molt, their appetite increases and they tend to feed primarily on the soft tissues surrounding the apical meristem. Mature grubs migrate to the periphery of the stem and prepare a cocoon made of palm fibers. After covering themselves with the cocoon, larvae enter a prepupal stage and then a pupal stage (Murphy and Briscoe, 1999). A new generation emerges and these adults may remain within the same host and reproduce until the palm meristem is destroyed resulting in the palm death. Subsequently, adults will fly away and look for new hosts.

2.1.1. Life cycle in Phoenix canariensis

The Canary Islands Date Palm, *Phoenix canariensis* hort. ex Chabaudis *R. ferrugineus* most susceptible host and its preferred host in the northern Mediterranean Basin. Although the life cycle of *R. ferrugineus* had been studied by some authors in different countries, on either artificial substrates or plant portions under controlled environmental conditions (Table 1), no results on the life cycle of *R. ferrugineus* in any of its hosts under natural conditions were available. Therefore, we decided to determine the thermal constant and the number of larval instars of *R. ferrugineus* when feeding in live *P. canariensis* palms under natural conditions in a Mediterranean climate (Dembilio and Jacas, 2011a). Based on measurements of the head capsule width, the existence of 13 larval instars in *R. ferrugineus* was established. Our results demonstrated that *R. ferrugineus* requires 40.4 DD for egg hatching under laboratory conditions, 666.5 DD for complete larval development in *P. canariensis* and another 282.5 DD to reach adulthood. Therefore, depending on mean temperatures, larval development can be completed in about 40 days in summer and up to 160 days in winter-spring. Likewise, pupae can complete their development in 13 days in summer but need several months to complete this stage from autumn to spring. Based on these results and on the temperatures in different climatic stations in the Iberian Peninsula, the mean number of generations of *R. ferrugineus* was estimated in the respective regions. These results indicated that less than one generation per year can be expected in areas with mean annual temperature (MAT) below 15ºC and more than two where MAT is above 19ºC (Dembilio and Jacas, 2011a). This is an important finding because we have observed that a minimum of two to three complete generations are necessary to kill an adult *P. canariensis*, and this means that at least two years would be necessary for *R. ferrugineus* to kill a palm in most of the Iberian Peninsula but more than these would be necessary in northern Spain and therefore a quarantine period of two years as it is nowadays required by EU laws (EU, 2007) could be insufficient to detect infested palms in that area. Should these results apply to other regions, a complete plus a partial generation per year would occur in most of the Northern shore of the Mediterranean Basin, whereas at least two complete generations per year would be expected in the Southern shore.

2.1.2. Lower temperature threshold for oviposition

Temperature is the main abiotic factor

Table 1. Development time and number of instars reported by different authors for *R. ferrugineus* feeding on different substrates.

Authors	Feeding substrate	Development time (days)				instars
		Egg	Larva	Pupa	Total	
Shahina *et al*., 2009	Honey in cotton	4-5	-	-	-	4
Shahina *et al*., 2009	Sugarcane lumps	4-5	50-80	20-30	74-115	9
Shahina *et al*., 2009	Apple slices	4-5	-	-	-	4
Abe *et al*., 2009	Apple slices	-	-	-	-	12
Salama *et al*., 2009	Banana slices	5	90	16-20	111-115	5
Salama *et al*., 2009	Sugarcane lumps	5	128	25-29	158-162	5
Salama *et al*., 2009	Squash fruit	5	83	20-24	108-112	5
Salama *et al*., 2009	Apple slices	5	103	16-18	124-126	5
Salama *et al*., 2009	Palm crown lumps	5	69	16-19	90-93	5
Kaakeh, 2005	Sugarcane lumps	3-4	82	19	108	-
Kaakeh, 2005	Palm Heart lumps	3-4	86	21	124	-
Kaakeh, 2005	Palm leaf base	3-4	84	18	119	-
Kaakeh, 2005	Artificial diet	3-4	70-102	16-23	93-131	-
Martín-Molina, 2004	Sugarcane lumps	3-4	88	25	116	11-17
Martín-Molina, 2004	Artificial diet	3-4	93	30	128	7-12
Martín-Molina, 2004	Palm lumps	-	-	-	-	8-15
Salama *et al*., 2002	Banana slices	-	-	13-22	-	-
Jaya *et al*., 2000	Sugarcane lumps	-	81-89	-	-	7
Esteban-Duran *et al*., 1998	Sugarcane lumps	-	76-102	19-45	139	-
Avand Faghih, 1996	Palm lumps	1-6	41-78	-	-	-
Kranz *et al*., 1982	NS	2-3	60	14-21	76-84	-
Kalshoven, 1981	Sago palm pith	-	-	-	105-210	-
Butani, 1975	Sugarcane lumps	2-4	24-61	18-34	44-100	-
Rahalkar *et al*., 1972	Sugarcane lumps	3-4	32-51	15-28	50-82	-
Nirula, 1956	Coconut slices	2-5	36-67	12-21	54-120	3
Viado and Bigornia, 1949	Coconut slices	3	35-38	11-19	49-70	9
Lepesme, 1947	NS	3	60	15	90-180	-
Dammerman, 1929	NS	3	60-120	14	74-134	-
Leefmans, 1920	Sago palm lumps	-	60	13-15	73-75	-
Ghosh, 1912; Ghosh, 1923	Palm lumps	3-4	25-61	18-33	48-82	-

NS: not specified

influencing the biology, ecology and population dynamics of poikilothermic organisms as arthropods. Once the thermal requirements of *R. ferrugineus* developing in live *P. canariensis* palms had been established, the next step focused on establishing the lower temperature thresholds for oviposition and egg hatching. The effect of temperatures in the range 10-25ºC on the reproductive parameters of laboratory-reared *R. ferrugineus*- was studied (Dembilio *et al.* 2011c). Highest fecundity and oviposition rate were observed at 25ºC, (33.25 eggs per female and 2.38 eggs per female and day, respectively), whereas no oviposition was observed for females kept below 15ºC. Interestingly, females moved from 25º to 15ºC at age 14 days old could lay a mean of 5.17 eggs during the entire experimental period (15 days) and those moved from 25º to 10ºC could lay

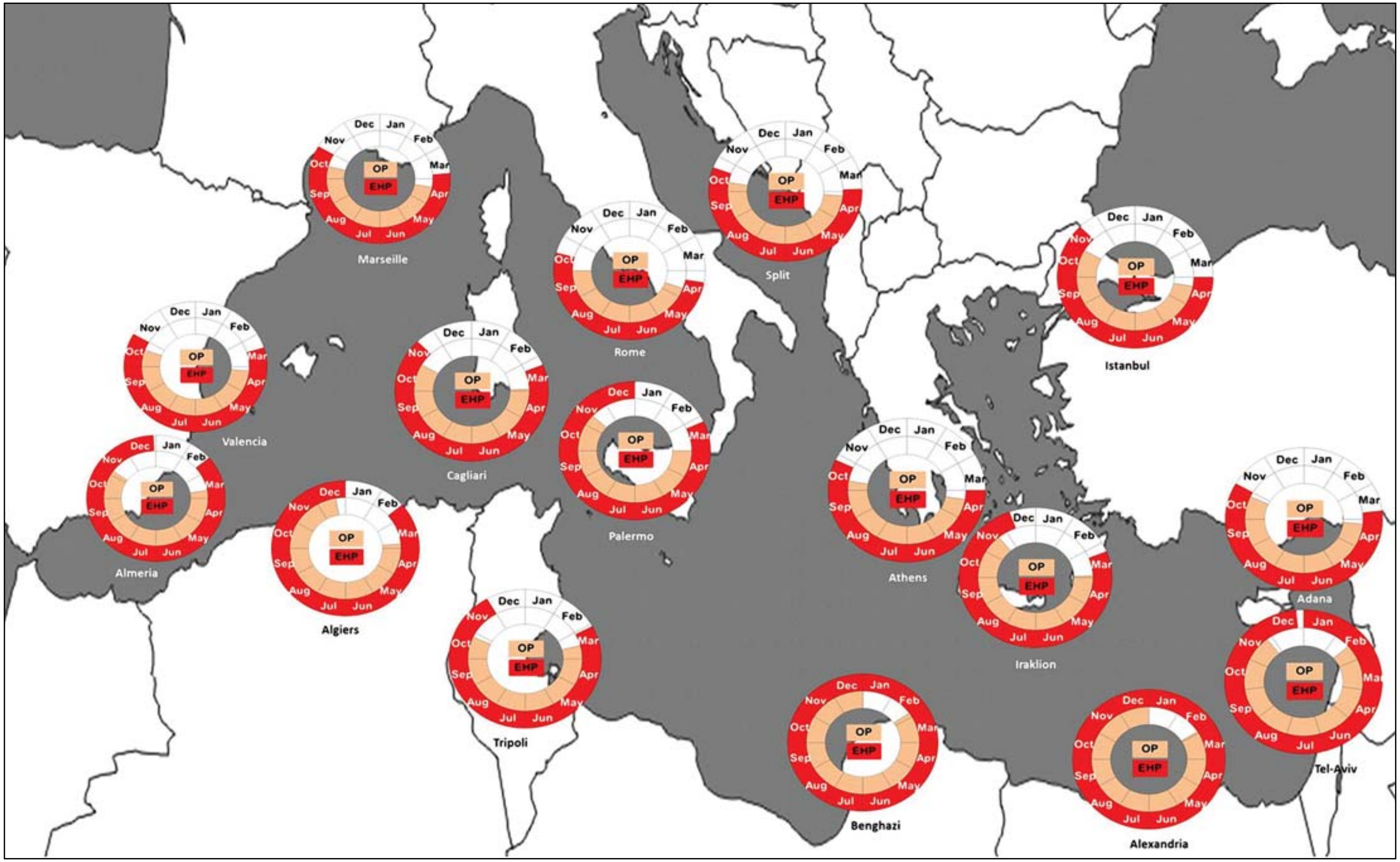

Figure 1. Estimated oviposition and egg hatching periods (OP and EHP, respectively) of *R. ferrugineus* based on mean monthly temperatures at some selected climatic stations in the Mediterranean basin.

0.75 eggs during the first 2 days of exposure to the lower temperature. Based on the results obtained at constant temperature regimes, a lower temperature threshold of 15.45ºC was estimated for oviposition. Taking into account all results obtained, a slightly lower value, 13.95ºC, was calculated for egg hatching. When these values were compared with mean monthly temperatures in Valencia and other selected locations in the Mediterranean Basin, windows for oviposition and egg hatching could be established (Figure 1). In most of the northern shore of the basin, the oviposition period (OP) extended from early April to mid-October early November and the egg hatching period (EHP) from mid-March to mid/late October. However, these periods were much shorter in the southern shore and although oviposition would stop during the coldest winter months, egg hatching would continue during the whole year in the southwestern part of the Basin (i.e. Egypt) (Dembilio *et al.*, 2011c). Based on these results, any management practice producing wounds (such as pruning or the cutting of an inspection window in the crown), should be best performed in winter, when oviposition is notably reduced and immature mortality is highest (Dembilio and Jacas, 2011a). Importantly, even during this season, all wounds should be immediately protected with a tree wound seal and, if possible, with an insecticide (Faleiro, 2006). For the same reason, the frequency of preventative treatments against the weevil could decrease during the winter, thus reducing the non-target effects of these pesticides.

2.2. Host range

Chamaerops humilis L. and *Phoenix theophrasti* Greuter are the two European native palm species and their host status was not clear. Barranco *et al.* (2000) considered *C. humilis* as resistant to the attack of *R. ferrugineus*. Nevertheless, the European Union included this species in the list of *R. ferrugineus*-susceptible plants (EU, 2007). This list also included the genus *Washingtonia* spp. However, in assays carried out by our group in 2007 (Llácer *et al.*, 2012), *Washingtonia filifera* (Lindl.) Wendl could not be infested with *R. ferrugineus* whereas *W. robusta* could. Different semi-field trials (Dembilio *et al.*, 2009) demonstrated that *W. filifera* and *C. humilis* could not be naturally infested by *R. ferrugineus* adult females. Antibiosis was the main, and perhaps the only, mechanism operating in *W. filifera*, as a gummy secretion produced by the plant resulted in complete mortality of *R. ferrugineus* young instars. Antixenosis was the major mechanism of resistance in the case of *C. humilis*. The base of the fronds of this palm is very fibrous and therefore not appropriate for oviposition. However, this antixenotic mechanism of resistance could be by-passed by artificially infesting the palm with neonate larvae deposited in holes made with a drill (Barranco *et al.*, 2000) and the same phenomenon was observed for *P. theophrasti* (Dembilio *et al.*, 2011b). Therefore, *C. humilis* and *P. theophrasti* palms formerly harmed either naturally (e.g. attacked by *Paysandisia archon* (Burmeister), damaged by the wind, etc.) or artificially (e.g. after trimming or pruning) could be attacked by *R. ferrugineus*, and this fact should be taken into account when dealing with these palm species.

3. Management of the Red Palm Weevil

3.1. Detection

A serious problem associated with *R. ferrugineus* is the difficulty of detecting the early stages of infestation (Nakash *et al.*, 2000). Because of the cryptic habits of *R. ferrugineus*, it is very difficult to detect infestations in their early stage. Unless palms are continuously thoroughly inspected, this pest is generally detected only after the palm has been severely damaged. Careful observation may expose the following signs which are indicative of the presence of the pest: dieback in the apical leaves in the canopy, where broken or cut leaves (symptom of larval damage to the meristem tissue) become visible, holes in the crown or trunk from which chewed-up fibers are ejected (this may be accompanied by the secretion of brown viscid liquid with a characteristic bitter smell), crown or frondloss and appearance of a dried off shoot are usually only visible long after the palm has become infested. Secondary infections of opportunistic bacteria and fungi may occur within injured tissues, accelerating the deterioration of palms.

As mentioned above, early detection of infested palms is very difficult but it is essential to ascertain the first symptoms as soon as possible in order to take appropriate measures. Currently, the use of bioacoustics and infrared systems or even the use of dogs can be employed with the aim of detecting early infestations (Faleiro, 2006). Future developments are expected and urgently needed.

3.2. Control

Because it is difficult to detect damage by *R. ferrugineus* during the early stages of infestation, emphasis is generally focused onpreventive measures mostly relying on chemical applications. Control methods against *R. ferrugineus* range from general dusting of the leaf axils with insecticides after pruning, or spraying of the palm tree trunk, to localized direct injections of chemicals into the trunk (Faleiro, 2006). All these treatments are often complemented with cultural and sanitary methods that include early destruction of infested plant material (Kurian and Mathen, 1971) and prophylactic treatment of cut wounds (Pillai, 1987). During the latest years, in the Region of Valencia, an integrated pest management (IPM) strategy has been implemented. This strategy includes (a) plant quarantine and plant certification, (b) mass trapping of adult weevils using ferrugineol-based food baited traps (Hallett *et al*., 1993), (c) crop and field sanitation, (d) preventive chemical treatments of gashes,(e) filling frond axils of young palms with a mixture of insecticides and (f) curative treatments of infested palms in the early stages of attack, eradicating severely infested palms. These palms should be removed and destroyed by shredding. Burning is not recommended as destruction means because palms do not burn easily and complete destruction of *R. ferrugineus* cannot be guaranteed in this case.

3.2.1. Chemical control

The most common and practical measure in chemical control is mainly based on the repeated application of large quantities of synthetic insecticides employed in a range of preventive and curative procedures designed to contain the infestation. These procedures have been developed and refined since commencing in India in the 1970's when work on application of organophosphates and carbamates ensured these chemicals to become the mainstay of the chemical approach to control *R. ferrugineus* (Murphy and Briscoe, 1999). In Spain, a minimum of 8 preventive treatments per season (from March to November) are recommended by the Valencian Department of Agriculture. However, only 4 active substances are nowadays authorized in palms against *R. ferrugineus*. These are Chlorpyrifos, Imidacloprid, Phosmetand Thiamethoxam (MARM, 2011). Some of these pesticides can be applied as spray on the stipe, injected into the trunk, or as a drench.

3.2.1.1. Systemic insecticides

Imidacloprid is a chloronicotinyl nitroguanidine systemic insecticide that has both contact and ingestion activity and works by disrupting the transmission of impulses in the nervous system of insects. It appears in the MARM list (MARM, 2011) under two different formulation categories, soluble concentrate (SL) and oil dispersion (OD), and it can be applied by spraying, injection or irrigation. The formulation, imidacloprid SL, was successfully tested by Kaakeh (2006), in laboratory and semi-field assays against *R. ferrugineus*. The OD formulation was recently tested by our group (Dembilio *et al*., 2010a; Llácer *et al*., 2012). Preventive and curative semi-field trials with imidacloprid OD applied by soil injection to *P. canariensis* showed 100 % and 94 % efficacies, respectively (Llácer *et al*., 2012). Furthermore, preventative treatments had high efficacy values, mean of 95.4 ± 2.7 %, for at least 45 days after application (Llácer *et al.*, 2012). In a field assay, two applications of imidacloprid OD per year successfully reduced mortality of *P. canariensis* palms to less than 27% compared to more than 84% for untreated control palms (Dembilio *et al.*, 2010a). Similar results were obtained by Tapia *et al.* (2011) in Southern Spain.

3.2.1.2.Insecticidal paints

The efficacy of an insecticidal paint based on chlorpyrifos and pyriproxyfen (1.5% and 0.063%, respectively) in a microencapsulated formulation was also studied by our group (Llácer *et al.*, 2010). This insecticidal paint was applied on the stipe and the base of the fronds of palms. Laboratory results showed that pyriproxyfen had no effect against *R. ferrugineus* when applied in this microencapsulated formulation and chlorpyrifos was the responsible of the efficacy of this product against the weevil. In semi-field assays, the paint was highly effective as preventive treatment. However, it was dismissed as curative insecticide. One single application of this paint could prevent infestation for up to 6 months with a mean efficacy of 83.3%.

3.2.2. Biotechnological control: semiochemicals

A very important component of any strategy against *R. ferrugineus* is mass trapping of adults using food baits. Ferrugineol (4-methyl-5-nonanol) is the major aggregation pheromone of the red palm weevil (Hallett *et al.*, 1993) and has been used in conjunction with 4-methyl-5-nonanone (Abozuhairah *et al.*, 1996) in mass-trapping programs which are widely practiced in several countries where red palm weevil is a problem (Abraham and Kurian, 1973; Hallett *et al.*, 1993; Vidyasagar *et al.*, 2000). Because (a) a trap set in an uninfested area can easily lead to its infestation by weevils responding to the attractive plumes coming from the trap and (b) a trap can highly increase the incidence of *R. ferrugineus* in an area if neighboring palms are not adequately protected, in Spain, mass trapping is only allowed under direct supervision of the local Department of Agriculture.

3.2.3. Biotechnological control: SIT

As a first step towards developing the Sterile Insect Technique (SIT) against *R. ferrugineus*, Al-Aydeh and Rasool (2010) studied the influence of gamma radiation on its mating behavior, and the efficacy of SIT under different levels of relative humidity. No adverse effects of gamma radiation were observed on the mating behavior parameters of theweevil. Furthermore, weevils were sexually stimulated during aggregation. However, as this weevil mates several times during its lifetime and its mass rearing is very expensive, the usefulness of this technique in this case remains quite doubtful.

3.2.4. Biological control

Reginald (1973) suggested that natural enemies do not play an important part in controlling *R. ferrugineus* and few studies have been conducted on *Rhynchophorus* spp. natural enemies (Faleiro, 2006; Murphy and Briscoe, 1999). There were some attempts in the laboratory and field using the predatory earwig *Chelisoches morio* (Fabricius) (Dermaptera: Chelisochidae) in India (Abraham and Kurian, 1973). However, it did not provide a measurable impact on the weevil. Although various mites have been reported in India as parasites of *R. ferrugineus* (Nirula, 1956; Peter, 1989), their impact on the population needs to be determined. Gopinadhan *et al.* (1990) reported that a cytoplasmic polyhedrosis virus infected all stages of the weevil in Kerala (India). Infected mature-larval stages resulted in deformed adults and severe suppression of the host population. In addition to these results, both entomopathogenic nematodes (EPN) and fungi (EPF) can provide an alternative to chemical control of *R. ferrugineus* (Dembilio *et al.*, 2011b; Dembilio *et al.*, 2010a; Dembilio *et al.*, 2010b; Faleiro, 2006; Llácer *et al.*, 2009; Tapia *et al.*, 2011). Unlike EPNs, EPFs infect the host by contact, then germinate and penetrate the insect cuticle. The host can be infected both by direct treatment and by horizontal transmission from infected insects or cadavers to untreated insects or to subsequent developmental stages via the new generation of spores (Lacey *et al.*, 1999; Quesada-Moraga *et al.*, 2004). These unique characters make EPFs especially important for the control of concealed insects as *R. ferrugineus*. Different strains of *Metarhizium anisopliae* (Metschnikoff) Sokorin (Ascomycota: Clavicipitaceae) and *Beauveria bassiana* (Balsamo) Vuillemin (Ascomycota: Clavicipitaceae) have been found in association with the weevil. Some of these EPFs strains were tested against *R. ferrugineus* (Gindin *et al.*, 2006). *Metarhizium anisopliae* proved more virulent than *B. bassiana*. However, none of the strains tested was originally obtained from diseased *R. ferrugineus* specimens. More recently, in preliminary studies, Sewify*et al.* (2009) successfully reduced the incidence of *R. ferrugineus* under field conditions in Egypt using a native strain of *B. bassiana* isolated from a *R. ferrugineus* cadaver.

3.2.4.1. Entomopathogenic nematodes: Steinernema carpocapsae

Although no entomopathogenic nematode has been naturally recorded infecting *R. ferrugineus*, *Steinernema carpocapsae* (Weiser) (Nematoda: Steinernematidae) proved effective against *R. ferrugineus* in semi-field trials including both preventive and curative assays (Llácer *et al.*, 2009). In a curative assay, efficacies around 80 % were obtained, and up to 98 % in a preventative treatment on *P. canariensis* (Llácer *et al.*, 2009). We have also proved the high efficacy of this treatment in *P. theophrasti* (Dembilio *et al.*, 2011b). Under field conditions, treatments using imidacloprid and *S. carpocapsae*, either alone or in combination were not significantly different from each other, with efficacies ranging from 73 to 95 % (Dembilio *et al.*, 2010a). Tapia *et al.* (2011) reached similar conclusions in field trials in Southern Spain. Therefore, EPNs should not be forgotten when developing strategies for treatments against *R. ferrugineus*.

3.2.4.1. Entomopathogenic fungi: Beauveria bassiana

In 2007, *R. ferrugineus* pupae presumed to be infected with EPFs were collected in a date palm grove in Spain (Dembilio *et al.*, 2010b). The *B. bassiana* strain isolated from these pupae proved to infect eggs, larvae and adults of *R. ferrugineus*. Furthermore, *B. bassiana* infection reduced adult lifespan from one half to almost one tenth. Adults of either sex inoculated with the fungus efficiently transmitted the disease to untreated adults of the opposite sex conferring rates of transmission between 55 and 60 %. In addition, treatment with this *B. bassiana* strain significantly reduced fecundity (up to 62.6 %) and egg hatching (32.8 %). Likewise, 30–35 % increase in larval mortality was observed in larvae obtained from eggs from fungus inoculated females or from untreated females coupled with inoculated males, resulting in an overall 78% progeny reduction compared to an untreated control. This strain was subsequently tested in semi-field preventive assays on potted 5-year old *P. canariensis* palms. Efficacies up to 85.7 % were obtained, and these results are indicative that contact infection of adults actually occurred and confirm the potential of this strain as a biological control agent against *R. ferrugineus*. Consequently, adults should be considered as the targets of any treatment involving this entomopathogenic fungus because are actually the only free-living stage. Strategies aimed at attracting and infecting adult weevils could prove the most effective way to spread the disease, and this is one of the works that our group is developing at this moment.

4. Conclusions

Washingtonia filifera is the only palm species included in our studies showing mechanisms of complete resistance against *R. ferrugineus*. This resistance is based on the production of an antibiotic exudate. However, the existence of additional mechanisms of resistance in this species cannot be excluded. Although *C. humilis* and *P. theophrasti* show antixenotic and antibiotic mechanisms of resistance, respectively, and larvae of the weevil suffer higher mortality in these host palms compared to *P. canariensis*, these mechanisms are not enough to prevent infestation. Therefore, these species cannot be considered as resistant against *R. ferrugineus*.

Under Mediterranean climate, the preimaginal development of *R. ferrugineus* in *P. canariensis* takes 666.5 DD and the weevil can complete 13 larval instars. Development under these conditions is faster than when fed on an artificial diet. Likewise, the number of larval instars is also lower. Based on the results obtained, less than one generation per year can be expected in areas with a mean annual temperature (MAT) below 15ºC and more than two in those with MAT above 19ºC. Because a minimum of 2-3 generations are necessary for the weevil to kill a *P. canariensis* palm, a minimum of two years are necessary for a new infestation to result lethal for a Canary Island date palm in most of the northern shore of the Mediterranean basin but shorter times would be expected in areas with higher MAT.

Oviposition in *R. ferrugineus* is strongly affected by temperature. The thresholds for oviposition and egg hatching obtained are very close to MAT registered in most of the northern shore of the Mediterranean basin and clearly below mean monthly temperatures in winter in this area. Under these circumstances, no new infestations would be expected during most of the winter. These results should be taken into account when planning some palm management practices such as pruning or pesticide treatments.

Both imidacloprid and *S. carpocapsae* in a chitosan formulation are highly effective against *R. ferrugineus* in the field. Different timings and product combinations were studied, and high efficacies were obtained in all cases. *Steinernema carpocapsae* was applied on a monthly basis and therefore resulted more expensive and time consuming than the drench applications of imidacloprid. However, this invertebrate biological control agent would be most suitable for ornamental palms in public areas.

An indigenous strain of *B. bassiana,* found naturally infecting pupae of *R. ferrugineus,* resulted highly virulent against all developmental stages of the weevil in the laboratory. Additionally, adults of either sex inoculated with the fungus efficiently transmitted the disease to healthy adults of the opposite sex. Furthermore, *B. bassiana* infection resulted in reduced fecundity and egg hatching. Semi-field preventive treatments on *P. canariensis* palms with this strain were highly effective against *R. ferrugineus* and this result confirmed the potential of *B. bassiana* as a biological control agent against this pest.

The UJI-IVIA group has received financial support from the Spanish Ministry of Science and Innovation (MCINN projects TRT2006-00016-C07-01 and AGL2008-05287-C04/AGR) and the Valencian Department of Agriculture, Fisheries and Food (CAPA, project IVIA-5611). Ó. Dembilio was recipient of a predoctoral grant from IVIA.

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Received:21 November 2011; Accepted:18 January 2012

ΑΡΘΡΟ ΑΝΑΣΚΟΠΗΣΗΣ

Βιο-οικολογία και ολοκληρωμένη αντιμετώπιση του ρυγχοφόρου των φοινικοειδών, *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae), στην περιοχή της Βαλέντσια (Ισπανία)

Ó. Dembilio και J.A. Jacas

Περίληψη Ο ρυγχοφόρος των φοινικοειδών, *Rhynchophorus ferrugineus* Olivier (Coleoptera: Curculionidae), είναι ένας από τους πιο καταστρεπτικούς εντομολογικούς εχθρούς των φοινικοειδών στον κόσμο. Έχει εξαπλωθεί σε όλες τις ηπείρους και έχει αναφερθεί σε 26 είδη φοινικοειδών από 16 διαφορετικά γένη. Στην λεκάνη της Μεσογείου, ο ρυγχοφόρος έχει αναδειχθεί στον σημαντικότερο εχθρό των φοινικοειδών, κυρίως του *Phoenix canariensis* hort. ex Chabaud, ενδημικό είδος των Καναρίων Νήσων που χρησιμοποιείται ευρέως ως καλλωπιστικό. Στην παρούσα εργασία συνοψίζονται τα αποτελέσματα ερευνητικής μελέτης που έχει γίνει για τον ρυγχοφόρο στο Πανεπιστήμιο UJI και το Ερευνητικό Ινστιτούτο IVIA της Ισπανίας. Πρώτος στόχος αυτής της μελέτης αυτής ήταν ο προσδιορισμός διαφορετικών βιο-οικολογικών παραμέτρων του *R. ferrugineus* στις συνθήκες του Μεσογειακού κλίματος. Από τα φοινικοειδή που μελετήθηκαν, μόνο το *Washingtonia filifera* εμφανίζει μηχανισμούς ανθεκτικότητας στο *R. ferrugineus*. Αν και τα φοινικοειδή *Chamaerops humilis* και *Phoenix theophrasti* εμφανίζουν μηχανισμούς άμυνας αλλά δεν μπορούν να θεωρηθούν ανθεκτικά στο *R. ferrugineus*. Η ανάπτυξη του *R. ferrugineus* στον Κανάριο φοίνικα, *P. canariensis,* στο Μεσογειακό κλίμα διαρκεί 666,5 ημεροβαθμούς και το έντομο μπορεί να συμπληρώσει 13 προνυμφικά στάδια. Σε περιοχές με μέση ετήσια θερμοκρασία μικρότερη από 15º C αναμένεται μια μόνο γενεά ενώ σε περιοχές με μέση ετήσια θερμοκρασία μεγαλύτερη από 19ºC, περισσότερες από δύο γενεές. Η ωοτοκία του *R. ferrugineus* επηρεάζεται επίσης από την θερμοκρασία. Η κατώτερη θερμοκρασία για ωοτοκία και εκκόλαψη των ωών του ρυγχοφόρου είναι κοντά στην μέση ετήσια θερμοκρασία στο μεγαλύτερο μέρος της βόρειας ακτής της Μεσογειακής λεκάνης. Κάτω από αυτές τις συνθήκες, δεν αναμένονται νέες προσβολές κατά το μεγαλύτερο μέρος του χειμώνα. Ο δεύτερος στόχος της μελέτης ήταν να βελτιωθεί η χημική και βιολογική αντιμετώπιση του εντόμου. Σκευάσματα φυτοπροστατευτικών προϊόντων με δραστική ουσία imidacloprid ή εντομοπαθογόνο νηματώδη *Steinernema carpocapsae* με χιτοζάνη ήταν πολύ αποτελεσματικά κατά του *R. ferrugineus* σε συνθήκες υπαίθρου. Δοκιμάστηκαν διάφοροι χρόνοι εφαρμογής και συνδυασμοί σκευασμάτων που έδειξαν υψηλή αποτελεσματικότητα σε όλες τις περιπτώσεις. Ένα ιθαγενές στέλεχος του *Beauveria bassiana,* το οποίο βρέθηκε να προσβάλλει νύμφες του *R. ferrugineus,* αποδείχτηκε πολύ αποτελεσματικό έναντι όλων των βιολογικών σταδίων ανάπτυξης του ρυγχοφόρου στο εργαστήριο. Επιπρόσθετα, ενήλικα άτομα και των δύο φύλων που είχαν εμβολιαστεί με τον μύκητα μετέδωσαν την ασθένεια σε υγιή ενήλικα του αντίθετου φύλου επιβεβαιώνοντας ότι το *B. bassiana* είναι εν δυνάμει παράγοντας βιολογικής αντιμετώπισης του εντόμου. Τα αποτελέσματα αυτά μπορούν να συμβάλλουν στην ανάπτυξη ενός προγράμματος ολοκληρωμένης αντιμετώπισης του ρυγχοφόρου.

Hellenic Plant Protection Journal **5:** 1-12, 2012