Pakistan J. Zool., pp 1-10, 2021. DOI: https://dx.doi.org/10.17582/journal.pjz/20210731060757

Review Article

Integrated Pest Management of *Rhynchophorus ferrugineus* Olivier: An Efficient Approach to Reduce Infestation in Date Palm Trees

Irshad Ahmad[1,2]*

[1]*Department of Bioengineering, King Fahd University of Petroleum and Minerals (KFUPM), Dhahran 31261, Saudi Arabia.*

[2]*Interdisciplinary Research Center for Membranes and Water Security, King Fahd University of Petroleum and Minerals (KFUPM), Dhahran 31261, Saudi Arabia.*

Article Information
Received 31 July 2021
Revised 23 September 2021
Accepted 01 October 2021
Available online 16 November 2021

Key words
***Phoenix dactylifera* L, *Rhynchophorus ferrugineus* Olivier, Red palm weevil, Integrated pest management, Biological control**

ABSTRACT

Date palm (*Phoenix dactylifera* L) is an essential fruit crop that is widely grown since ancient times in the desert areas of the world comprising the Southwest Asia, North Africa besides Mexico, Australia, South America, and United States. A number of insect pests including red palm weevil (*Rhynchophorus ferrugineus* Olivier) that is a devastating insect attacking palm trees. It is very difficult to control as its entire lifecycle is hidden inside the host trunk. To overcome this pest, integrated pest management program (IPM) strategy can be adopted that includes visual inspection, behavior management through pheromones, sanitation of the crop and field, removal of the infested frond and offshoot, eradicating the concealed breeding sites of the pest. IPM also include cultural techniques comprising in-groove humidity and palm density, judicious use of insecticides, using biological control agents including entomopathogenic fungi, nematodes as well as adopting the regulatory methods of domestic and international quarantine. This paper provides updated information about IPM, which look like a promising paradigm that can be adopted for the control of red palm weevil.

INTRODUCTION

Date palm tree (*Phoenix dactylifera* L.) is an ancient crop grown in Southwest Asia, North Africa as well as Mexico, Australia, and some states of the United States. It needs a warm dry climate for flowering and fruits ripening (Allbed *et al*., 2017). It is an economical and ideal food crop for the poor people in developing countries facing with micronutrient deficiencies (Shabani *et al*., 2016). Due to its increasing consumption the top date palm growing countries have produced ~ 3.5 million metric tons in 1990 that was increased by > 7.5 million metric tons in 2014 (Al-Alawi *et al*., 2017). Dates contain plentiful quantity of carbohydrates > 80% of its dry matter and other important nutrients such as iron, potassium, calcium, magnesium, and polyphenols (Maqsood *et al*., 2020). Numerous health benefits have been associated with these polyphenols that play a significant role in the bioactivities such as antioxidant, anticarcinogenic, antimutagenic, and anti-inflammatory (Bentrad and Ferhat, 2020).

Several arthropod pests including 112 species of mite and insect pests that are distributed among 10 orders and 42 families can damage the date palm. Among the mentioned species, red palm weevil (*Rhynchophorus ferrugineus* Olivier, RPW) is reflected as a devastating insect pest of date palm tree (El-Shafie, 2012). While its first report from India (Ghosh, 1912), RPW is nowadays widely distributed among 54 countries of the world attacking 32 species of date palm (CABI, 2020). According to the Ministry of Agriculture (MOA) of Saudi Arabia, it was first time recorded to attack date palm trees in Alqatif area of the Eastern province in 1987. Within 2 years, it was consequently reported in the regions of Riyadh and Tabuk. Currently, it has been distributed to nine regions of KSA including Eastern, Riyadh, Albahah, Alhail, Alqassim, Makkah, Madinah, Tabuk, and Najran (MOA, 2014).

Red palm weevil (RPW) is very difficult to control as it completes most of its lifecycle hidden inside the palm tree and its control is mainly chemical based using synthetic pesticides (Hussain *et al*., 2016). Though, pesticides cannot control RPW infestation that not only jeopardize the biological diversity but also dangerous for the surrounding environment (Abdel-Raheem *et al*., 2020; Hussain *et al*., 2016; Al-Ayedh *et al*., 2016). Therefore, keeping in view, the toxic effects of pesticides on human health and their environmental issues an alternative ecofriendly strategy of integrated pest management (IPM) needs to

* Corresponding author: irshad@kfupm.edu.sa
0030-9923/2021/0001-0001 $ 9.00/0

be implemented for the control of RPW (Mendesil *et al.*, 2016). Presently, all participants in the agricultural value chain have been agreed on the judicious use of pesticides and to implement IPM as an ecofriendly paradigm in plant protection (Pretty and Bharucha, 2015; Rossi *et al.*, 2019; Sawinska *et al.*, 2020). The IPM approach encompassed regular field visits to detect pest damage, using plant-sanitation tools to eliminate the hidden breeding places containing abandoned date plantations by restricting palm damage, judicious use of pesticides, removing sternly infested palms, employing quarantine procedures, education, and training of agriculturalists (Sallam *et al.*, 2012; Al-Dosary *et al.*, 2016; Faleiro *et al.*,2018).

LIFE CYCLE OF RPW

Life cycle of RPW is completed in 3-4 months (varies due to season) in 5 stages (egg, larvae, pupal, cocoon and adult). Generally, the male and female adults' mate numerous times and the female frequently lays 200-400 eggs during its lifespan. The eggs are whitish yellow colored with 1mm in width and 3mm in length. The female burrows holes in the palm tree with its mouthparts and lays eggs that takes 2-5 days to hatch, and larvae appear. The larvae are creamy colored with reddish head with 13 segments existed on the body. The larval stage is considered as very destructive with strong mouthparts digging tunnels inside the palm and greedily feeds on its tender tissues. The entire larval stage is completed inside the palm passed through numerous molting phases for a period of 5-15 weeks depending on seasonal temperature. The last phase of larvae stops feeding and starts cocoon synthesis (1-3 days) from the fibers and tissues of palm tree for pupation. The pupal stage is inactive that lasts in 10-20 days and appear as an adult weevil that are reddish brown in color with 42mm in length and 16mm in width. The adult RPM still live inside the damaged palm tree until the conditions changed and become unsuitable for their stay. During these circumstances, the adult come outside the palm tree and flies to a new one, guided by pheromones released by its counterpart and/or by kairomones emitted by other palm trees (Soroker and Colazza 2017; Nangai and Martin, 2017). Figure 1 represents the different stages of RPW life cycle.

RPW DAMAGING SYMPTOMS IN THE HOST

The RPW generally attack its host (*Phoenix dactylifera*) in the basal part of the tree trunk. The symptoms can be observed by yellowish ooze secretions that seeping out of the infested palm trunk that become dark brown colored dried gum with the passage of time and an unpleasant odor impending from the damaged tissue and the larva waste. In advanced stage, the holes in trunk connected to tunnels and internal cracks are filled with the shewed tissue. With time pass, the damage become severe and the trunk usually break down with strong winds (FAO, 2020).

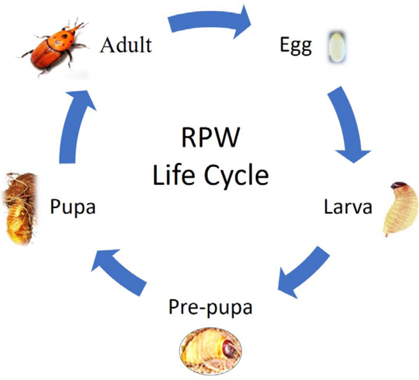

Fig. 1. Different stages of RPW life cycle (FAO, 2020; Nangai and Martin, 2017).

In rare cases, RPW causes apical infestation that can be observed by excessive and distorted growth of some fronds that deviate from their original place, forming voids in the date palm summit. With passage of time the fronds become dry and fall over with cocoons scattered around the date palm trunk and in the end, the whole summit of the palm falls on the ground (Nasraoui, 2020).

IPM PARADIGM FOR RPW CONTROL

IPM is an ecofriendly and green strategic plan having the potential to control RPW. The main constituents of IPM include consistent farm visits to detect early palms infestation, using food-baited pheromone traps for capturing adult weevils, judicious use of insecticides, removal of infested palms and hidden breeding sites, good agronomic practices for field cleanliness, palm thickness, irrigation, removal of frond and offshoot. Additionally, biological control agents including fungi and nematodes as well as proper quarantine procedures to control the movement of planting material (FAO, 2020). Table I displays main features of the IPM paradigm for the control of RPW.

EARLY DETECTION OF RPW INFESTATION

Date palm growers have to make regular visits to inspect trees and detect RPW in the early stage of their

Table I. Main features of the integrated pest management paradigm for the control of RPW.

Control method	Main features of the control method	References
Regular inspection	Regular visits to detect early infestation Use of cutting-edge pest detection tools Observation and monitoring of the pest	Ashry *et al*., 2021 Wang *et al*., 2021
Agronomic practices	Adaptation of good agronomic practices Put on adequate irrigation system in the fields Abide by good tilling before planting Keep proper space between date palms	Ben Salah, 2019 Dewidar *et al*., 2016
Mechanical control	Removal of the infested date palms Proper disposal of weeds and dry trunks Closing all openings in the palm trunks	FAO, 2020
Pheromone traps	Using cutting-edge semiochemical control Using cost effective pheromone trapping Improve the longevity of pheromone lures Using long lasting kairomones food baits	Llopis *et al*., 2018 Yan *et al*., 2021
Chemical control	Judicious use of curative chemical treatments Effective strategy of stem injection method Spraying according to experts recommendations	Chihaoui-Meridja *et al*., 2020 Al Ballaa *et al*., 2020
Biological control	Using effective parasites and predators of RPW Testing new biological control agents of RPW Development of biopesticides for RPW control	Al-Jassany and Al-Asaeedi, 2019 Yasin *et al*., 2017
Legislative control	Implementation of strict quarantine regimes Prevent transfer of infested trees or offshoots Phytosanitary legislation and establishing standard tissue culture laboratories	Balijepalli and Faleiro, 2019 Fajardo, 2020

attack. In this regard, farmers must be properly trained to detect RPW symptoms in the infested host by visual inspection as well as using the cutting-edge tools for the earlier detection of the hidden pest. Currently an optical-fiber-distributed acoustic sensor (DAS) was used for the quick recognition of RPW that can detect the feeding sound of a very young larva of 12 days. This new technology deliver 24-7, concurrent checking of >1,000 date palms as well as monitor the temperature to avoid any form fire (Ashry *et al*., 2020).

Currently, the combined technology of machine learning and fiber optic distributed acoustic sensing (DAS) system was used for the early detection of RPW. The farm conditions have been mimicked in a laboratory comprised a tree infested by 12-day-old larvae of RPW compared with a healthy tree. In the meantime, noise sources are acquaint with sounds of wind and bird nearby the trees. Subsequently exercise through experimental time and frequency domain data delivered by the fiber optic DAS system with a totally linked artificial neural network (ANN) and a convolutional neural network (CNN) are able to competently distinguish the healthy and infested date palms with tremendously précised statistics for ANN 99.9 and CNN with 99.7% under rational noisy circumstances. This is an economical and efficient system that can be implemented to monitor the early finding of RPW in the infested palm fields (Wang *et al*., 2021).

Another study has reported the use of ecofriendly optical tool containing digital and thermal cameras, TreeRadarUnitTM (radar 2000, radar 900), resistograph, magnetic DNA biosensor, and NIRS for the timely detection of RPW in date palm trees in fields. The resistograph and NIRS have shown significant prospective to detect RPW in the infested date palms (Rasool *et al*., 2020).

APPLICATION OF IMPROVED AGRONOMIC PRACTICES

The most important constituent of IPM is the use of improved agronomic practices in date palm farming include selection of pest resistant varieties, irrigation system, palm density, field sanitation, frond pruning and offshoot elimination, adopted to dropdown the level of RPW infestation (Ben Salah, 2019). According to a study ~ 90% of the infestations ensued on the palm trunk between 0-100 cm from the ground and 36% infestation level has been noted in 6-10 years old date palm. Moreover, 79% infestation was recorded in date palms without any off shoots, showing that offshoots removal from date palm is exposing it to RPW attack particularly after pruning of fronds. Close spacing between palms at planting and open flood irrigation enhances RPW attack due to higher humidity in cultivated area (Sallam *et al*., 2012). Many date palm growers are still using the flood irrigation that assist infestation of RPW entry in the date palm trunk. Therefore, new sub-surface irrigation methods have been developed that are advantageous in saving water resources; evade weeds survival and pest's hibernation in the base of date palm tree (Dewidar *et al*., 2016).

Currently RNA interference (RNAi) is becoming a prevailing approach intended for the promising control of RPW. RNAi was investigated in RPW by silencing three genes (α-amylase, V-ATPase, Ecdysone receptor). Every gene function was determined by testing two different doses (1,500 and 5,500 ng) with two delivery methods (injection and ingestion), to knockdown both genes and ultimately death of the insects. It was found that RNAi mediated gene silencing in RPW differs with every gene and a stronger retort was observed when dsRNA was directed by injection. These results portray a new strategy to develop pest resistant varieties through RNAi against RPW (Laudani *et al*., 2017).

MECHANICAL CONTROL OF RPW

Removal of the rigorously damaged date palm is a significant part of RPW-IPM program because the damaged host sheltering adult weevils with coinciding generations of the pest, which needs an immediate removal. Therefore, before emergence of the adults that can cause new infestation their subsequent host needs a proper removal from infested farms. Numerous date palm growers merely cut the infested palm and throw it nearby the farmstead, which is not a good exercise to eliminate the damaged host. Some of the growers just cut the damaged tree trunk into 2-3 parts and burn it nearby the farm. As burning big sections of tree trunk does not destroy the larvae or cocoons concealed inside the stem or palm crown. Therefore, as a preventive level, immerse, soak or dip the palm crown, tree trunk with galleries sections with a recommended pesticide (FAO, 2020).

PHEROMONE TRAPS FOR CONTROL OF RPW

Currently majority of date palm growers control RPW by using synthetic pesticides. However, pesticides do not efficiently control RPW; jeopardize biodiversity, and non-ecofriendly. Additionally, the excessive use of pesticides is responsible for the development of resistance in RPW against these insecticides (Al-Ayedh *et al*., 2016). Therefore keeping in view the environmental and human health hazards, pheromone trapping is a wise strategy for the economical and eco-friendly control of RPW. Researchers have reported the preeminent trapping practices vis-a-vis pheromone attraction, food-bait, trapping mass, location and overhauling (Oehlschlager, 2016; Llopis *et al*., 2018).

Pheromone trapping is a vital component of IPM program to catch RPW. In different field experiments various traps were evaluated including stump trap, lure synergist ethyl acetate, kairomones, lures, yeast, and food baits. These traps experiments show different catchability of RPW, the co-attractants were found as the crucial trap constituents and novel findings in co-attractant blends as an attraction for the development of food-bait free traps (Abdel-Azim *et al*., 2017). Plants essential oils (PEO) have been investigated to determine its efficacy against the egg and larval stages of RPW. Five PEO (orange, lemon, eucalyptus, castor, and basil oil) and three mixtures K1 (chilli, thyme and lavender), K2 (Colocynth and neem), and K3 (Radicchio, turmeric and Silene) with 5 concentrations of 1, 3, 5, 7 and 9% of each one was used in 3 replicates with ten eggs or larva. The five PEOs shown significant toxicity against eggs and larvae stages, which portrays it as ecofriendly pesticides for the IPM program (Ali *et al*., 2019).

Currently the effect of EOs (purslane, mustard and castor) in (bulk and nano) was determined against RPW larvae, pupae and adults. Purslane oil was very effective shown percent mortality of larvae as 75.2, 45.3 and 17.9% in bulk phase and 92.5, 84.4 and 65.5% in the nano phase followed by mustard and castor. The ovipositional activity as reduced with cumulative meditation of the verified EOs (Abdel-Raheem *et al*., 2020). Similarly, EO byproducts of eugenol and thymol have been confirmed as significant bioinsecticides to control the fourth instar larvae of RPW. Altered meditations of these byproducts in biological replicates in lieu of 14 days was determined to check the feeding contact bioassay. The derivatives of eugenol and thymol presented significant antifeeding bustle against the larvae of RPW (Yan *et al*., 2021).

Recently, nano-gels pheromone was evaluated to attract RPW adults by pheromone traps matched with the normal one for two consecutive periods in 2018 and 2019. In this study, two types of traps (traditional and dry funnel trap) were compared to check the capturing efficiency of RPW adults. It was observed that compared to normal traps the nano gel pheromone traps in field shown better catchability of RPW adults by 22.51 and 18.30% of total RPW adults captured in two consecutive periods respectively (El-Wahab *et al*., 2021). Another study was conducted to find out the food intake and developing phase of RPW larvae on three diets e.g., coconut cabbage, oil palm cabbage and sago stem while the proteins analysis of RPW larvae intestinal systems was determined. The purpose of these experiments was to investigate the influence of various diets on the proteomic profiles of the digestive systems that can be used as prospective tool for RPW control (Zulkifli *et al*., 2018).

CHEMICAL CONTROL OF RPW

The control of the aggressive RPW is still a big challenge for palm growers due to its larval instars hidden inside the host that are endophytic and cannot be controlled by cover sprays. Therefore, an effective chemical control strategy of stem injection method or endotherapy has been applied by using systemic and persistent insecticides. This method was applied on ornamental palm trees in Tunisia and Italy, during 2015-2018, via emamectin benzoate, thiamethoxam, and imidacloprid to check the efficacy, mobility, and perseverance of these insecticides. The emamectin benzoate was found as systemic and persistent ~ 5 months in palm tissues compared to thiamethoxam and imidacloprid (Chihaoui-Meridja *et al*., 2020). In another study, the sensitivity of RPW larvae has been investigated in Makkah AL Mukarramah region by checking the efficacy of three pesticides Fiprol (cyclodines), Imidaprid (neonicotinoid) and Dueracide (organophosphate) via feeding and dipping methods. Fiprol was found to be more effective against RPW larvae with LC50 of 0.896-71.2 ppm followed by Dueracide and Imidaprid respectively (Mohammed *et al*., 2020).

The mechanical sanitization or injecting insecticide into the damaged palms usually does not eradicate the pest hidden in the palm. Therefore, a different fumigation method was used to treat infested palms through aluminium phosphide capsules (3g) confirming ample trap of phosphine gas that was tried on 295 RPW damaged palm trees in different phases of outbreak in Al-Qassim region, during 2017-2018. This method was tried in young and old palms trees concluded with field trials to heighten the number of applied doses, treatment time and type of wrap for the gas entrapment. It was observed that young date palms with a onetime use of 10 aluminium phosphide capsules for 5 days while in offshoots, 15 aluminum phosphide tablets for 15 days ensured death of larva to adult phases of RPW. This method is becoming popular and can be used for quarantine control of date palm offshoots in Saudi Arabia (Al-Ballaa *et al*., 2019). Similarly, another study was conducted to test six common insecticides used in different amounts to control RPW in mild and severely infested date palms. A 100% mortality of the pest inside the infested palms was observed in 5 days by the fumigant action of the insecticides treatments with 120 ml of Deltamethrin (10% EC), 150 ml of Chlorpyriphos (48% EC), 150 ml of MarqiuseTM (combination of Phoxim 15%, Cypermethrin 5%, and Monosultap 20%), 150 ml of Malathion (57% EC), 150 ml of Diazinon (60% EC) and 250ml Cypermethrin (25% EC). These results shows a better alternative to control RPW with aluminum phosphide or trunk injection methods (Al Ballaa, 2020).

Excessive use of pesticides has resulted in the development of resistance in RPW in the date palms growing areas of Pakistan. The resistance was evaluated via food fusion technique in contradiction of the formulated insecticides profenophos, imidacloprid, chlorpyrifos, cypermethrin, deltamethrin, spinosad, lambda-cyhalothrin and a fumigant phosphine. High intensities of resistance was noted for cypermethrin, deltamethrin and phosphine due to their excessive use in Pakistan. Resistance Ratios (RRs) of 63-79, 16-74, 13-58, 2.6-44, 3-24, 2-12 and 1-10 fold was determined in phosphine, cypermethrin, deltamethrin, profenophos, chlorpyrifos, lambda-cyhalothrin and spinosad compared to the susceptible control line (Wakil *et al*., 2018).

Due to the environmental concerns, a biopesticide (Emamectin benzoate) has been investigated for its toxicity against insects and borers to protect trees from insect pests (Mashal and Obeidat, 2019). Recently it was used through Syngenta Tree Micro-Injection method for controllong RPW. 100% mortality of RPW (larval and pupal stages) was observed in the infested date palms (Rasool *et al*., 2021). In another study, the efficacy of oxamyl was determined against RPW larvae and adults. During laboratory and field trials, it was highly effective against RPW in the infested date palms (Alhewairini, 2018). Recently, a pesticide of bacterial source (Spinosad) was investigated against RPW females. A lethal dose aimed at 50% of the treated females was intended at 44.3 ppm. The efficacy of different spinosad concentrations (10, 50 and 200 ppm) on the catalase (CAT), glutathione S-transferase (GST) and superoxide dismutase (SOD) activities have been accessed in ovaries of RPW. A significant increase in CAT activity was observed at 200 ppm. This study shows the possible application of spinosad to control the RPW females in the infested date palms (Abdelsalam *et al*., 2020).

BIOLOGICAL CONTROL OF RPW

Due to concealed nature of the RPW and non-target effects of comprehensive spraying an interest has been developed in the scientific community to focus on the environmental friendly biological agents (microbial entomopathogens) for the control of RPW (Yasin *et al*., 2017). Different pathogens and parasites have been surveyed in Iraq that can effectively control the larval and adult stages of RPW. A virus (*Oryctes*), which causes sluggish movement, infected its larvae stop feeding, white spots found below the skin and proliferation of the infected abdomen. Subsequently, larval body changed to a transparent liquid with chalky look, ultimately causes the death of insect. A bacterium (*Pseudomonas* sp.) was detected in the infected larvae that become blue colored, with passage of time turn black and finally become dead with a stinking smell. Moreover, an entomopathogenic nematode (*Steinernema* sp.) was also found to attack the larval stage of the insect and causing its death. Similarly, an entomopathogenic fungus (*Beauveria bassiana*) was identified that infects the insect larvae having white hypha on the larval bodies that finally get dry. Additionally, mites (*Sancassania* sp., *Pergamasus* sp. and *Rhizoglyphus robini*) have been found to parasitize both larvae and adults of RPW. In this study 20 mites/insect have been identified that causes 100% mortality of RPW in 10 days after infestation (Al-Jassany and Al-Asaeedi, 2019).

The entomopathogenic fungus (*Beauveria bassiana*) was investigated by spraying of fungus conidiospores on the larvae and adults of RPW in research laboratory. The larvae and adults were given the tissue incisions of internal stem of the damaged date palms as a natural food by testing 6 consecutive concentrations from 6 x 10^2 to 6 x 10^7 spores/ml. Maximum mortality rates was recorded in the tested 3rd instar larvae while all the tried concentrations showed 100 % mortality (El-Husseini, 2019). In another study, the virulence exerted by fungal spores and silver Nano-particles (AgNPs) from entomopathogenic fungi (EPF) was tested against RPW in the laboratory settings. Different quantities of the fungal spores and AgNPs were sunthesized from *Metarhizium anisopliae*, *Beauveria bassiana*, and *Verticillium lecanii*. The 3 EPF have shown 70-90% death rates in egg phase in 7 days. *M. anisopliae* and *B. bassiana* have shown significant efficacy. Adult death rate was 70% in 7 days, when tried with *M. anisopliae*, 60% with *B. bassiana*, and 53% with *V. lecanii* (Abdel-Raheem *et al*., 2019).

In laboratory settings, the entomopathogenic fungi (*Beauveria bassiana*) and insecticides (Nitenpyram Active 10% SL) were used in different concentration against RPW larval instars, pupal and adult stages. This combined application of fungi and insecticide was very effective with synergistic effects against RPW showing highest mortality (100%) in second instar larvae as compared to late instars. This indicates the necessity of linking *B. bassiana* with a bioinsecticide that can decrease the management cost as well as ecofriendly and non-harmful against natural enemies (Qayyum *et al*., 2020). Similarly, an entomopathogenic nematode and imidacloprid were used alone and in combinations to check its efficacy against three larval stages and adult RPW as well as at sub-lethal doses its pupation rate, adult emergence and egg eclosion were investigated. A high mortality rate in the larval stages and adults of RPW was observed in combined treatments as compared to single treatments. Moreover, egg eclosion, pupation and adult emergence were lowest in combined use of EPN and imidacloprid. These findings could contribute to the effective management of RPW, particularly in zones wherever it has established pesticide resistance (Arshad *et al*., 2020).

Recently the in vitro and in vivo effects of serine protease inhibitors (SPIs) action counter to RPW have been verified in date's kernel (DKE) crude extract, host and Calotropis latex (CLE), non-host. Both DKE and CLE PIs inhibited some kinds of intestinal proteases existed in the midgut of RPW. The decrease in intestinal proteases by DKE and CLE was 39%, 18%, correspondingly while the larvae nourishing on PIs CLE and DKE show significant mortality. The data proposes host and nonhost PIs as bioactive valuable source of bio-pesticides that can be implemented in future due to its eco-friendly nature (Orfali *et al*., 2020).

LEGISLATIVE CONTROL OF RPW

Due to the rapid spreading of RPW strict quarantine, regimes and directives need to be implemented to restraint the pest to other subcontinents. The pest has been reported in many North African countries excluding Algeria raised many inquiries that why the pest did not reached there. Stringent quarantine processes have been adopted in countries such as Morocco, Tunisia, Algeria, Libya and Mauritania to restraint RPW at estuary up to 2008, however except Algeria the pest spread to the neighbor countries. This clearly shows that strict quarantine practices can limit the spread of the pest (Balijepalli and Faleiro, 2019). In Spain RPW in the Canary Islands have been effectively controlled due to strict implementation of RPW-IPM program. RPW were detected in 2005 and the following years however due to the strict vigilant policy the islands was declared free of RPW by May 2016 (Fajardo, 2020).

The Algerian government has implemented very strict quarantine regimes on the transportation of planting material in order to control RPW infestation. Additionally, FAO has promoted tissue culture technology in Morocco and Algeria (Bouguedoura *et al*., 2015). However, RPW is a solemn pest in the Meghreb countries; RPW nevertheless reported from Algeria that is confirmed by CABI (CABI, 2018). It has been reported that RPW arrived in Libya, Morocco, Mauritania, Oman, Egypt, Iran, Iraq, Qatar, Yemen, Palestine, Tunisia and Saudi Arabia, due to damaged date palm offshoots, ornamental palms and mountaineering on vehicles. Therefore, strict quarantine regulations need to be implemented to prevent the spread of RPW within the national as well as international borders. In this regard, phytosanitary regulations and recommendations have been prepared in 2018 mission on phytosanitation and quarantine protocols for KSA that might assist as per plans on quarantine matters against RPW. The explicit procedures include phytosanitary legislation particularly palm tree checkups, infested palms removal, palms movement and treatment protocols, palm nurseries certification according to IPPC standards (ISPM 36) with establishing standard tissue culture laboratories to expedite RPW free planting material throughout the region (Balijepalli and Faleiro, 2019).

CONCLUSIONS

This article provides updated information for the control of RPW through integrated pest management (IPM) that seems to be an auspicious stratagem for the effective control of RPW. The IPM program will set up a paradigm to significantly reduce the infestation of RPW in the date palm producing countries of the world. The IPM strategy described here would be valuable to eliminate RPW infestation in date palms with simultaneous economic profits for the farmer community of the region.

ACKNOWLEDGMENTS

The author highly acknowledges the Department of Bioengineering, King Fahd University of Petroleum and Minerals (KFUPM), Dhahran, Kingdom of Saudi Arabia for the conduction of this study.

Statement of conflict of interest

The author has declared no conflict of interest.

REFERENCES

Abdel-Azim, M.M., Aldosari, S.A., Mumtaz, R., Vidyasagar, S.P.V., and Shukla, P., 2017. Pheromone trapping system for *Rhynchophorus ferrugineus* in Saudi Arabia: Optimization of trap contents and placement. *Emir. J. Fd. Agric.*, **29**: 936-948. https://doi.org/10.9755/ejfa.2017.v29.i12.1564

Abdel-Raheem, M., ALghamdi, H.A., and Reyad, N.F., 2020. Nano essential oils against the red palm weevil, *Rhynchophorus ferrugineus* olivier (coleoptera: Curculionidae). *Entomol. Res.*, **50**: 215-220. https://doi.org/10.1111/1748-5967.12428

Abdel-Raheem, M.A., ALghamdi, H.A., and Reyad, N.F., 2019. Virulence of fungal spores and silver nano-particles from entomopathogenic fungi on the red palm weevil, *Rhynchophorus ferrugineus* Olivier (Coleoptera: Curculionidae). *Egypt. J. Biol. Pest. Contr.,* **29**: 97. https://doi.org/10.1186/s41938-019-0200-2

Abdelsalam, S., Alzahrani, A.M., Elmenshawy, O.M., and Abdel-Moneim, A.M., 2020. Antioxidant status and ultrastructural defects in the ovaries of red palm weevils (*Rhynchophorus ferrugineus*) intoxicated with spinosad. *Entomol. Res.*, **50**: 309-316. https://doi.org/10.1111/1748-5967.12442

Al-Alawi R.A., Al-Mashiqri J.H., Al-Nadabi J.S.M., Al-Shihi B.I., and Baqi Y., 2017. Date Palm Tree (*Phoenix dactylifera* L.): Natural Products and Therapeutic Options. *Front. Pl. Sci.,* **8**: 845. https://doi.org/10.3389/fpls.2017.00845

Al-Ayedh, H., Hussain, A., Rizwan-ul-Haq, M., and Al-Jabr, A.M., 2016. Status of insecticide resistance in field-collected populations of *Rhynchophorus ferrugineus* (olivier) (coleoptera: Curculionidae). *Int. J. Agric. Biol.*, **18**: 103-110. https://doi.org/10.17957/IJAB/15.0070

Al-Ballaa, S.R., 2020. Fumigant action of commonly used insecticides as a curative treatment of red palm weevil *Rhynchophorus ferrugineus* (Olivier) in infested date palms. *Arab J. Pl. Prot.*, **38**: 333-338.

Al-Ballaa, S.R., and Faleiro, J.R., 2019. Studies on curative treatment of red palm weevil, *Rhynchophorus ferrugineus* Olivier infested date palms based on an innovative fumigation technique. *Arab J. Pl. Prot.,* **37**: 119-123. https://doi.org/10.22268/AJPP-037.2.119123

Al-Dosary, N.M., Al-Dobai, S., and Faleiro, J.R., 2016. Review on the management of red palm weevil *Rhynchophorus ferrugineus* olivier in date palm *Phoenix dactylifera* L. *Emir. J. Fd. Agric.*, **28:** 34-44. https://doi.org/10.9755/ejfa.2015-10-897

Alhewairini, S.S., 2018. Laboratory and field evaluation of the toxicity of oxamyl against the red palm weevil, *Rhynchophorus ferrugineus* (Olivier). *Pakistan J. Zool.*, **50**: 249-256. https://doi.org/10.17582/journal.pjz/2018.50.1.249.256

Ali, M.A., Mohanna, K.M., Mohamed, G.S., and Allam R.O.H., 2019. Efficacy of some promising plant essential oils to control the red palm *weevil Rhynchophorus ferrugineus olivier* (coleoptera: curculionidae) under laboratory conditions. *SVU Int. J. Agric. Sci.,* **1**: 12-22. https://doi.org/10.21608/svuijas.2019.67092

Al-Jassany, R.F., and Al-Asaeedi, H.M.L., 2019. Associated entomopathogens and parasitoids of palm rhinoceros beetle, *Oryctes* spp. (Coleoptera:

Dynastidae) on date palm in Iraq. *Arab J. Pl. Prot.,* **37**: 251-258. https://doi.org/10.22268/AJPP-037.3.251258

Allbed, A., Kumar, L., and Shabani, F., 2017. Climate change impacts on date palm cultivation in Saudi Arabia. *J. Agric. Sci*., **155**: 1203-1218. https://doi.org/10.1017/S0021859617000260

Arshad, A., Munawar, A., Mastoi, M.I., Sohail, S., Bashir, F., and Liang, C., 2020. The compatibility of single and combined applications of the entomopathogenic nematode, *Heterorhabditis indica* with imidacloprid against red palm weevil, *Rhynchophorus ferrugineus* (Oliv.). *Asian J. Agric. Biol*., **8**:315-322. https://doi.org/10.35495/ajab.2020.01.021

Ashry, I., Mao, Y., Al-Fehaid, Y., Al-Shawaf, A., Al-Bagshi, M., Al-Brahim, S., Ng, K.T. and Ooi, B.S., 2020. Early detection of red palm weevil using distributed optical sensor. *Sci. Rep*., **10**: 3155. https://doi.org/10.1038/s41598-020-60171-7

Balijepalli, S.B., and Faleiro, J.R., 2019. Is policy paralysis on quarantine issues in the Near East and North Africa region leading to the buildup and spread of red palm weevil, *Rhynchophorus ferrugineus*? *Arab J. Pl. Prot.,* **37**: 89-100. https://doi.org/10.22268/AJPP-037.2.089100

Ben Salah, M., 2019. Importance of field operations for reducing red palm weevil (RPW) infestation on date palm. *Arab J. Pl. Prot*., **37**: 159-162. https://doi.org/10.22268/AJPP-037.2.159162

Bentrad, N., and Ferhat, A.H., 2020. Date palm fruit (Phoenix dactylifera): Nutritional values and potential benefits on health. In: *The Mediterranean diet* (eds. V. Preedy and R. Watson). Academic Press. pp. 239-255. https://doi.org/10.1016/B978-0-12-818649-7.00022-9

Bouguedoura, N., Bennaceur, M., Babahani, S., and Benziouche, S.E., 2015. Date palm status and pespective in Algeria. In: *Date palm genetic resources and utilization. Volume 1: Africa and the Americas* (eds. J.M. Al-Khayri, S.M. Jain and D.V. Jhnson). Springer, Germany. **4**: 125-168. https://doi.org/10.1007/978-94-017-9694-1_4

CABI, 2018. *Rhynchophorus ferrugineus* (red palm weevil). https://www.cabi.org/isc/datasheet/ 47472.

CABI, 2020. *Rynchophorus ferrugineus* (red palm weevil). Invasive species compendium datasheet https://www.cabi.org/isc/datasheet/47472. Accessed on March 20th, 2020.

Chihaoui-Meridja, S., Harbi, A., Abbes, K., Chaabane, H., Pergola, A.L., Chermiti, B. and Suma, P., 2020. Systematicity, persistence and efficacy of selected insecticides used in endotherapy to control the red palm weevil *Rhynchophorus ferrugineus* (Olivier, 1790) on *Phoenix canariensis*. *Phytoparasitica*, **48**: 75-85. https://doi.org/10.1007/s12600-019-00776-5

Dewidar, Z.A., Al-Fehaid, Y., Al-Hilal, S., and Ben Salah, M., 2016. Water saving in Arid Regions: A comparison of Surface and subsurface drip irrigation systems. *Am. J. Res. appl. Sci*., **2**: 289-296.

El-Husseini, M.M., 2019. Efficacy of the fungus *Beauveria bassiana* (Balsamo) Vuillemin on the red palm weevil *Rhynchophorus ferrugineus* Olivier (Coleoptera: Curculionidae) larvae and adults under laboratory conditions. *Egypt. J. Biol. Pest. Contr.,* **29**: 58. https://doi.org/10.1186/s41938-019-0155-3

El-Shafie, H.A.F., 2012. Review: List of arthropod pests and their natural enemies identified worldwide on date palm, *Phoenix dactylifera* L. *Agric. Biol. J. North Am*., **3**: 516-524. https://doi.org/10.5251/abjna.2012.3.12.516.524

El-Wahab, A.S.A., El-Fattah, A.Y.A., El-Shafei, W.K.M., and Helaly, A.A.E., 2021. Efficacy of aggregation nano gel pheromone traps on the catchability of *Rhynchophorus ferrugineus* (Olivier) in Egypt. *Braz. J. Biol*., **81**: 452-460. https://doi.org/10.1590/1519-6984.231808

Fajardo, M., Rodríguez, X., Hernández, C.D., Barroso, L., Morales, M., González, A. and Martín, R., 2020. The eradication of the invasive red palm weevil in the Canary Islands. In: *Area-wide integrated pest management, development and field application* (eds. J. Hendrichs, R. Pereira and M.J.B. Vreysen) 1st edn. pp. 539–550. CRC Press, Boca Raton, Florida, USA.

Faleiro, J.R., Ferry, M., Yaseen, T. and Al-Dobai, S., 2019. Overview of the gaps, challenges and prospects of red palm weevil management. *Arab J. Pl. Prot.,* **37**: 170-177.

FAO, 2020. Food and Agriculture Organization of the United Nations. *Red palm weevil: Guidelines on management practices.* Rome. Italy. pp 86.

Ghosh, C.C., 1912. Life history of indian insects-III. The Rhinoceros beetle (*Oryctes rhinoceros*) and the red palm weevil (*Rhynchophorus ferrugineus*). *Ent. Ser*. **11**: 203-218.

Hussain, A., Rizwan-ul-Haq, M., Al-Ayedh, H., AlJabr, A.M., 2016. Susceptibility and immune defence mechanisms of *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae) against entomopathogenic fungal infections. *Int. J.*

mol. Sci., **17**: 1518. https://doi.org/10.3390/ijms17091518

Laudani, F., Strano, C.P., Edwards, M.G., Malacrinò, A., Campolo, O., Abd El Halim, H.M., Gatehouse, A.M. R., and Palmeri, V., 2017. RNAi-mediated gene silencing in *Rhynchophorus ferrugineus* (Oliver) (Coleoptera: Curculionidae). *Open Life Sci*., **12**: 214-222. https://doi.org/10.1515/biol-2017-0025

Llopis, N.V., Primo, J., and Vacas, S., 2018. Improvements in *Rhynchophorus ferrugineus* (Coleoptera: Dryophthoridae) trapping systems. *J. econ. Ent*., **111**: 1298-1305. https://doi.org/10.1093/jee/toy065

Maqsood, S., Adiamo, O., Ahmad. M. and Mudgil, P., 2020. Bioactive compounds from date fruit and seed as potential nutraceutical and functional food ingredients. *Fd. Chem.,* **308**: 125522. https://doi.org/10.1016/j.foodchem.2019.125522

Mashal, M.M., and Obeidat, B.F., 2019. The efficacy assessment of emamectin benzoate using micro injection system to control red palm weevil. *Heliyon,* **5**: e01833. https://doi.org/10.1016/j.heliyon.2019.e01833

Mendesil, E., Shumeta, Z., Anderson, P., and Rämert, B., 2016. Smallholder farmers' knowledge, perceptions and management of pea weevil in north and north-western Ethiopia. *Crop Prot*., **81**: 30-37. https://doi.org/10.1016/j.cropro.2015.12.001

MOA, 2014. *The current distribution of red palm weevil in the Kingdom of Saudi Arabia*. Ministry of Agriculture, Riyadh.

Mohammed, A.O.W., Mahyoub, J.A., and Alghamdi, K.M., 2020. Evaluation of fiprol, imidaprid and dueracide insecticides against larval stage of red palm weevil *Rhynchophorus Ferrugineus* (Olivier) in Makkah Al-Mukarramah Region. *Biosci. Biotechnol. Res. Asia*, **17**: 319-327. https://doi.org/10.13005/bbra/2835

Nangai, V.L., and Martin, B., 2017. Interpreting the acoustic characteristics of Rpw towards its detection. A review. *IOP Conf. Ser. Mater. Sci. Eng*., **225**: 012178. https://doi.org/10.1088/1757-899X/225/1/012178

Nasraoui, B., 2020. Red palm weevil (*Rhynchophorus ferrugineus*): Proposition of a simple and low-cost control workplan. Flehetna (http://flehetna.com), January 2021, Tunisia, pp. 12.

Oehlschlager, A.C., 2016. Palm weevil pheromones-discovery and use. *J. chem. Ecol*., **42**: 617-630. https://doi.org/10.1007/s10886-016-0720-0

Orfali, R., Binsuwaileh, A., Abu Al-Ala'a, H., Bane-Gamea, S., Zaidan, N., Abdelazim, M., Ismael, M.A., Parveen, S., Majrashi, N., Alluhayb, K. and Orfali, R.S., 2020. Production of a biopesticide on host and Non-Host serine protease inhibitors for red palm weevil in palm trees. *Saudi J. biol. Sci*., **27**: 2803-2808.

Pretty, J., and Bharucha, Z.P., 2015. Integrated pest management for sustainable intensification of agriculture in Asia and Africa. *Insects,* **6**: 152-182. https://doi.org/10.3390/insects6010152

Qayyum, M.A., Saleem, M.A., Saeed, S., Wakil, W., Ishtiaq, M., Ashraf, W., Ahmed, N., Ali, M., Ikram, R.M., Yasin, M., Maqsood, M., Kiran, S., Qaiser, M.F., Ayaz, R.A., Nawaz, M.Z., Abid, A.D., Khan, K.A. and Alamri, A.A., 2020. Integration of entomopathogenic fungi and eco-friendly insecticides for management of red palm weevil, *Rhynchophorus ferrugineus* (Olivier), *Saudi J. biol. Sci*. **27**: 1811-1817. https://doi.org/10.1016/j.sjbs.2019.12.018

Rasool, K.G., Husain, M., Salman, S., Tufail, M., Sukirno, S., Mehmood, K. Farooq, W.A. and Aldawood, A.S., 2020. Evaluation of some non-invasive approaches for the detection of red palm weevil infestation. *Saudi J. biol. Sci*., **27**: 401-406. https://doi.org/10.1016/j.sjbs.2019.10.010

Rasool, K.G., Salman, S., Abbas, N., Mehmood, K., Sutanto, K.D., and Aldawood, A.S., 2021. Toxicity and field efficacy of emamectin benzoate (ARETOR) against Red Palm Weevil, by using Syngenta Tree Micro-Injection Technique. *Int. J. Agric. Biol.,* **25**: 1120-1125. https://doi.org/10.17957/IJAB/15.1771

Rossi, V., Sperandio, G., Caffi, T., Simonetto, A., and Gilioli, G., 2019. Critical success factors for the adoption of decision tools in ipm. *Agronomy*, **9**: 710. https://doi.org/10.3390/agronomy9110710

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

Sawinska, Z., Switek, S., Głowicka-Wołoszyn, R., and Kowalczewski, P.T., 2020. Agricultural practice in poland before and after mandatory IPM implementation by the European union. *Sustainability*, **12**: 1107. https://doi.org/10.3390/su12031107

Shabani, F., Kumar, L., Nojoumian, A.H., Esmaeili, A., and Toghyani, M., 2016. Projected future distribution of date palm and its potential use in alleviating micronutrient deficiency. *J. Sci. Fd.*

Agric., **96**: 1132-1140. https://doi.org/10.1002/jsfa.7195

Soroker, V., and Colazza, S., 2017. *Handbook of major palm pests: Biology and management*. Wiley Blackwell, Ed. UK, pp. 316. https://doi.org/10.1002/9781119057468

Wakil, W., Yasin, M., Qayyum, M.A., Ghazanfar, M.U., Al-Sadi, A.M., Bedford, G.O., and Kwon, Y.J., 2018. Resistance to commonly used insecticides and phosphine fumigant in red palm weevil, *Rhynchophorus ferrugineus* (Olivier) in Pakistan. *PLoS One,* **13**: e0192628. https://doi.org/10.1371/journal.pone.0192628

Wang, B., Mao, Y., Ashry, I., Al-Fehaid, Y., Al-Shawaf, A., Ng, T.K., Yu, C., and Ooi, B.S., 2021. Towards detecting red palm weevil using machine learning and fiber optic distributed acoustic sensing. *Sensors,* **21**: 1592. https://doi.org/10.3390/s21051592

Yan, T.K., Asari, A., Salleh, S.A., and Azmi, W.A., 2021. Eugenol and thymol derivatives as antifeedant agents against red palm weevil, *Rhynchophorus ferrugineus* (Coleoptera: Dryophthoridae) larvae. *Insects,* **12**: 551. https://doi.org/10.3390/insects12060551

Yasin, M., Wakil, W., El-Shafie, H.A., Bedford, G.O., and Miller, T.A., 2017. Potential role of microbial pathogens in control of red palm weevil (*Rhynchophorus ferrugineus*). A review. *Entomol. Res*., **47**: 219-234. https://doi.org/10.1111/1748-5967.12221

Zulkifli, A.N., Zakeri, H.A., and Azmi, W.A., 2018. Food consumption, developmental time, and protein profile of the digestive system of the red palm weevil, *Rhynchophorus ferrugineus* (Coleptera: Dryophthoridae) larvae reared on three different diets. *J. Insect Sci*., **18**: 10. https://doi.org/10.1093/jisesa/iey093