Proceedings

International Webinar

Advances in Red Palm Weevil Research and Management

(International Year of Plant Health Event)

8th September 2020

Organized by

Don Bosco College of Agriculture

Sulcorna, Quepem - Goa, India

(Affiliated to: **GOA UNIVERSITY**)

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Compiled and Edited by

Rajan Shelke
and
J. R. Faleiro

DBCA

Don Bosco College of Agriculture

Sulcorna, Quepem - Goa, India

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International Webinar

Advances in RPW Research and Management

(International Year of Plant Health Event)

Dr. Chandrika Mohan
ICAR-CPCRI, Regional Station,
Kayangulam, Kerala, India

Topic: Advances in RPW-IPM in Coconut

Dr. Hamadttu El-Shafie
Date Palm Research Center of Excellence, KFU, Al-Ahsa,
Saudi Arabia

Topic: Current Challenges of RPW Management & Impact of COVID-19 Pandemic on Global Date Palm Production

Dr. Jose Romeno Faleiro
Goa, India

Topic: Evolving Trends in Semiochemical Mediated Technologies against RPW

Prof. (Dr.) Hassan Al-Ayedh
KACST, Riyadh, Saudi Arabia

Topic: Global View of Red Palm Weevil (RPW) *Rhynchophorus ferrugineus* with Emphasis on Saudi Arabia and Selected G20 Countries

Dr. Michel Ferry
Phoenix Research Station
Elche, Spain

Topic: Another Conception of Preventive & Curative Treatments for the control of RPW.

Date: 8th Sep 2020 (2 Hours Webinar)
Start Time: 2.00 pm India
(12.30 pm Dubai, 11.30 am Riyadh, 10.30 am Cairo and Paris, 6.30am Brisbane)

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Organizers

Prof. Rajan Shelke
Ms. Sulochana Xete Dessai
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Foreword

Dr Suresh Kunkalikar,
Principal, Don Bosco College of Agriculture

It gives me immense pleasure to announce the first International Webinar on "Advances in Red Palm Weevil Research and Management" organized by the Department of Agricultural Entomology under the leadership of Prof Rajan Shelke, in association with Dr. J. R. Faleiro. I express my sincere thanks to FAO of the UN for designating the webinar as an 'International Year of Plant Health' event (http://www.fao.org/plant-health-2020/events/events-detail/en/c/1306417/).

Red palm weevil is a major pest and production constraint of coconut, date palm and oil palm, commercially grown across the world. In Europe, red palm weevil is a key pest of the canary island palm. Globally the pest is currently being reported from nearly 50 countries.

In Goa coconut is cultivated in about 24,000 ha area with an annual production of 110 million nuts providing livelihood security to thousands of farm families. As in several States of India, coconut is an integral part of the daily cuisine in Goa and is closely associated with the life and tradition of the people in India.

The Webinar on this key pest of palms generated a lot of interest from participants across the world. The Don Bosco College of Agriculture profusely thanks the speakers; Prof. (Dr.) Hassan Al-Ayedh (KASCT-Riyadh, Saudi Arabia) , Dr. Chandrika Mohan (ICAR-CPCRI, Kayangulam, Kerala, India), Dr. Hamadttu El-Shafie (DPRCE-KFU, AlAhsa, Saudi Arabia), Dr. Michel Ferry (Phoenix Research Station, Elche, Spain) and Dr. J. R. Faleiro (Goa, India) for acceding to requests to share their experience on red palm weevil that was very well received by the participants. Mr. Sandeep Faldesai, Managing Director of Goa State Horticultural Corporation, Govt of Goa kindly agreed to deliver the inaugural remarks and set the tone for the meeting.

I look forward for many such webinars on different topics for the benefit of farmers, growers, entrepreneurs, technical experts, government officials and policy makers. This proceeding of the Webinar will serve as a valuable document on the latest technologies related to the research and management of the red palm weevil.

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Contents

Global View of Red Palm Weevil (RPW) *Rhynchophorus ferrugineus* with Emphasis on Saudi Arabia and Selected G20 Countries

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Abstract

During the last three decades the red palm weevil (RPW) *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae) has emerged as a key pest of palms in diverse agro-ecosystems, including Saudi Arabia and other G-20 countries. During 2017 FAO hosted a global meeting on RPW and called for coordinated action at the national, regional and global levels to combat the pest. In spite of there being several research publications and ongoing research on RPW there is an urgent need to address the shortfalls of the current RPW-IPM strategy which mainly revolves around visual detection of infested palms, pheromone trapping to capture adult weevil, preventive and curative chemical treatments and removal of severely infested palms. Large scale movement of planting material has resulted in the quick spread of the pest, calling for the implementation of strict quarantine protocols. This article gives a global overview on the situation in the G-20 countries with focus on Saudi Arabia.

Key words: *Rhynchophorus ferrugineus*, IPM, G-20 countries

Introduction

The red palm weevil (RPW) *Rhynchophorus ferrugineus* (Olivier) is a key pest of palms in diverse agro ecosystems worldwide. During the last three decades the spread of the pest has been rapid mainly due to the large scale movement of planting material both for farming and ornamental gardening (FAO, 2017). Fresh wounds on frond bases (petioles) attract gravid females for oviposition which results in infestation (Abraham *et al.*, 1998).

RPW is a cryptic hidden pest extremely difficult to detect when palms are in the early stage of attack, which respond to curative insecticide treatments. Palms in the late stage of attack exhibiting more than 30% tissue damage have to be removed and safely disposed. Globally there are several research groups investigating on a diverse aspects of RPW control including early detection, biological control, phytosanitary treatments, semiochemical mediated technologies, chemical treatments, etc. However, there exist several challenges that need to be addressed to refine the current RPW strategy. Recently FAO has embarked on a mega-research program on RPW involving countries of the Near East and North Africa (NENA) region. Saudi Arabia is playing a major role in promoting this project both through funding and carrying out research activities identified through six technical working groups.

This article gives a global overview on RPW with focus on Saudi Arabia and selected G-20 countries.

- **Identification of RPW**

Scientific Name: *Rhynchophorus ferrugineus* (Olivier)

Common name: Red Palm Weevil

Order: Coleoptera

Family: Curculionidae

Origin of the Pest: Indian Sub-Contient

RPW adults can be sexed based on the tuff of bristles on the snout. Male weevils exhibit bristles on the dorsal side of the snout, while this is absent in female weevils (Figure 1).

Male **Female**

Figure 1. Identifying male and female adult RPW based on tuff of bristles on the snout

- **<u>RPW Life Cycle</u>**

A good understanding of the life cycle of RPW is essential to effectively manage the pest. There are several reports on the biology and life cycle of RPW. Recently Al-Ayedh, 2020 in the FAO guidelines on RPW management summarized previous reports and gave a detailed account on the life cycle of this pest. Depending on the host and prevailing weather conditions the entire life cycle is completed in 45-139 days. Following is the duration of RPW life stages;

Egg: 3-5 days

Larval period: 45-60 days

Pupal stage: 60-90 days

Adult stage: 2-3 months

In areas with a mean annual temperature (MAT) below 15^{o}C, one generation per year can be expected while more than two generations in those with MAT above 19^{o}C. Several overlapping generations of the pest may occur inside a single infested palm (Dembilio and Jacas, 2011).

- **<u>Global Spread of RPW:</u>**

In 1980's RPW was recorded in Saudi Arabia, and during the last three decades its spread has been rapid after it gained entry in the Arabian Peninsula through ornamental palm shipments during the mid-1980s. Currently the pest is being reported in nearly 50 countries (EPPO, 2020). Following are the countries in which RPW is reported from different geographical regions of the world.

Far East: Cambodia, China, Hong Kong, Indonesia, Japan, Laos, Malaysia, Myanmar, Philippines, Singapore, Taiwan, Thailand, Vietnam.

South Asia: Pakistan, India, Bangladesh, Sri Lanka

Arabian Peninsula: Bahrain, Cyprus, Egypt, Iran, Iraq, Jordan, Kingdom of Saudi Arabia, Kuwait, Lebanon, Palestine, Qatar, Sultanate of Oman, Syria, Turkey, United Arab Emirates, Yemen.

Africa: Djibouti, Egypt, Libya, Mauritania, Morocco, Tunisia

Europe: Albania, Bosnia and Herzegovina, Croatia, Cyprus, France (mainland, Corse), Georgia, Greece (mainland, Kriti), Israel, Italy (mainland, Sardinia, Sicilia), Jordan, Malta, Montenegro, Morocco, Portugal (mainland, Madeira), Russia (Southern Russia), Spain (mainland, Islas Baleares), Tunisia, Turkey

Americas: Aruba, Netherlands Antilles

The pest was previously reported from the Oceanic region and also from USA but these reports is currently attributed to other *Rhynchophorus* weevils. During 2019, RPW was detected in Bulgaria in the Black Sea Basin region and also in Bosnia-Herzegovina in Southeastern Europe.

- **Host Plants Attacked by RPW:**

Like the geographical spread the host range has also dramatically increased over the years. From just four host palms (*Cocos nucifera*, *Phoenix dactylifera, Metroxylon sagu* and *Corypha umberaculifera*) in the 1950s (Nirula, 1956), RPW is currently reported on 40 palm species worldwide http://www.savealgarvepalms.com/en/weevil-facts/host-palm-trees

The current host range of RPW (Anonymous, 2013) is as follows;

including *Areca catechu* L., *Arenga saccharifera* Labill, *A. engleri* Becc., *A. pinnata* (Wurmb), *Bismarckia nobilis* Hildebr and Wend, *Borassus flabellifer*L., *Borassus* sp., *Brahea armata* S. Watson, *B. edulis, Butia capitata* (Mart.) Becc., *Calamus merrillii*Becc., *Caryota cumingii*Lodd., *C. maxima* Blume, *Cocos nucifera*, *Corypha utan*Lamk., (= *C. gebanga*, *C. elata*), *C. umbraculifera* L., *Chamærops humilis*, *Elaeis guineensis, Livistona australis* (R.Br.) Mart., *L. Decipiens* Becc., *L. Chinensis* Jacq. R. Br., *L. saribus* (= *L. cochinchinensis*) (Lour.) Merr., *Metroxylon sagu* Rottb., *Oncosperma horrida* (Scheff.), *O. tigillarium* (Ridl.), *Phoenix canariensis* (Chabaud), *P. dactylifera*, *P. Roebelinii* O'Brien, *P. Sylvestris* Roxb, *P. Theophrastii* Greuter, *Pritchardia pacifica* Seemann and Wendl and, *P. Hillebrandii* (Kuntze) Becc., *Ravenea rivularis* Jumelle and Perrier, *Roystonea regia* (Kunth.), *Sabal umbraculifera* (Jacq.) Martius, *Trachycarpus fortunei*(Hook), *Washingtonia filifera* (L. Lindl), *W. robusta* H. Wendl., and *Syagrusr omanzoffiana* (Cham.). The non-palm hosts are the century plant *Agave americana* and sugarcane *Saccharum officinarum*.

- **RPW Damage Symptoms**

Complete knowledge of the damage symptoms is essential to detect a RPW infested palm. Currently detecting RPW infested palms is mostly by visual inspection. Recently (FAO, 2020), have given detailed description of the symptoms due to RPW damage in date palm and the Canary island palm. While infestation in date palm is mainly restricted on the trunk close to the ground, in male date palm and the canary palm infestation due to RPW is in the crown. Gravid female weevils are attracted to palm volatiles for egg laying. Upon hatching, the larvae tunnel into the palm. As feeding progresses, frass (chewed palm tissue with palm fluid) is seen protruding from the palm emitting a fermented smell. Palms with <30% tissue damage are amenable for treatment by stem injection. Palms with >30% tissue damage have to be removed. Severely infested palms often harbor overlapping generations of the pest and topple and fall. In date palm drying of the water shoots on the trunk is a sign of RPW infestation.

- **RPW Epidemiology Data**

Modest quarantine measures for plant importation

Large scale movement of planting material both for farming and ornamental gardening, coupled with the lack of treatment protocols and weak enforcement of quarantine regulations has contributed to the spread of RPW (FAO, 2017). FAO has recently published detailed guidelines on phytosanitary regulations to be adopted against RPW (Chouibani, 2020).

Favorable weather conditions

Although RPW has its home in South and South East Asia where humid tropical conditions prevail, the pest has found a suitable ecological niche both in the dry hot and arid climatic conditions of the Middle East where it is a key pest of date palm, and also in the Europe on the Canary island palm where cool and temperate weather conditions exist. Ecological niche modeling predicts that this pest can expand its range to other ecosystems (Fiaboe *et al.*, 2012).

Susceptible host plant species

Most of the popular date palm cultivars are also suitable to RPW. Host plant resistance has not been fully studied and exploited with regard to RPW in spite of some preliminary research that has characterized palm cultivars in term of tolerance/susceptibility to RPW (Al Ayedh, 2008; Dembilio *et al.*, 2009). Screening techniques to identify resistant RPW cultivars and parental material for use in breeding programs need to be developed.

Lack of natural enemies

Lack of effective biological control agents against RPW in the field is a major concern that needs to be addressed to strengthen the ongoing RPW control strategy. Several biological control agents have been reported against RPW agents (Mazza *et al.*, 2014). Most promising among these being, entomopathogenic nematodes *Steinernemasp sp.* (Dembilio *et al.*, 2010) and entomopathogenic fungi *Beauveria bassiana* (Gűerri-Agulló *et al.*, 2011; Hussain *et al.*, 2015). While these are efficacious in the laboratory and semi-field assays, refinement in technologies pertaining to delivery to the target site and sustenance in the field needs to be addressed, if biological control is going to be used as an IPM tool against RPW.

Good flyer

RPW is predominantly a diurnal flyer (Aldryhim and Al Ayedh, 2015). Flight mill studies have demonstrated that RPW has the capacity to fly up to 50 km in a day. A sizeable population is short distance fliers (<100m) which would explain the aggregated/clumped distribution of infestation (Ávalos *et al.*, 2014; Hoddle *et al.*, 2015).

- **Management Technology for RPW**

The management of RPW can be broadly categorized into i) diagnostic techniques to detect RPW infestation, ii) monitoring technologies, iii) border control measures, iv) preventive measures (among G-20 countries) and v) control measures

Diagnostic techniques to detect RPW infestation

Detection of infested palms is considered as a milestone before applying control measures. Unavailability of early detection instruments is the major challenge faced by countries with the RPW problem. There are numerous detection technologies under different stages of development. The implementation of measures for early detection will help to stop the spread and infestation due to RPW. Currently visual detection by manually inspecting palms is widely practiced. However, following detection techniques to detect infest palms are being refined and developed for use in the field: detecting chemical signatures by sniffer dogs, detecting chemical signatures by E-nose, low-power image sensors, acoustic detection, thermal imaging, near infra-red detection, laser induced breakdown spectroscopy (LIBS), high frequency radar, X-ray technology etc.

Monitoring Technologies

Pheromone (ferrugineol) traps are able to detect the adult population in an infested area and have been widely used in surveillance and mass trapping programs. It is essential to adopt the best trapping protocols while using RPW pheromone traps. Aldhryhim, and Al-Ayedh, (2015), have developed and tested smart traps for RPW, but these need advancement for large scale deployment in the field. An ideal RPW pheromone trap would be one that does not need servicing and automatically transmits weevil capture data on a 24x7 basis to the operations control unit.

Border measures to avert RPW introduction

a) **At the local/national level**

- ✓ Stopping the nursery stock movement from RPW infested areas
- ✓ Developing certification and registration system for date palm nurseries
- ✓ Raising awareness among all stakeholders especially farmers about the phytosanitary measures of RPW
- ✓ Adoption and enforcement of phytosanitary measures regarding date palm cultivation
- ✓ Regulating the movement of date palms within the country through traceability
- ✓ Developing coordination to strengthen the engagement among farmers, officials and cooperatives on the development of pest free nurseries

b) At the regional/global level

- ✓ Strong commitment towards compliance with quarantine enforcement
- ✓ Stop the interference of higher officials on matters related to the trade of palms
- ✓ Build capacities of all stakeholders
- ✓ Promote use of in-vitro propagated palms

Lack of awareness among the stakeholders has largely contributed to the failure for the implementation of quarantine regulations. In this context awareness on quarantine regulations needs to be enhanced by maintaining/implementing:

- ✓ Strict quarantine regulations.
- ✓ Government check on the recommended regulations.
- ✓ Penalties for violators.

- ✓ Government incentives for the production of pest-free nurseries.
- ✓ Efficient surveillance program.
- ✓ Social engagement by organizing farmer's corner meetings about the Good Agricultural Practices for palms and their nurseries will significantly help to raise awareness.

- ***<u>Management technology for RPW: Current situation in KSA</u>***

FAO has listed the guidelines for the management of RPW (FAO, 2020). The Kingdom of Saudi Arabia, implements a national program encompassing various RPW-IPM techniques to control RPW. The strategy is implemented with the active support and coordination of the Directorates of Agriculture in different Provinces of the Kingdom under the supervision of the Ministry of Agriculture, Water and Agriculture (MEWA). Due to the consistent efforts of MEWA the infestation levels have steadily dropped over the years and during 2020 infestation level of 0.55% was reported.

- ***<u>Preventive measures among the G20 countries</u>***

Following are the highlights of RPW preventive measures adopted in some of the G-20 countries:

- ✓ Japan: Uprooting and burning the infested palms is the main preventive measure.
- ✓ Brazil (RPW free at present): much focus remains on the augmentation and conservation of natural enemies of pests as preventive measure in order to tackle the possible invasion of RPW.
- ✓ Turkey: the use of pheromone traps is the main preventive measure.
- ✓ Kingdom of Saudi Arabia: pheromone traps, uprooting and safe disposal of severely infested palms, and regular cultural practices (such as minimizing the humidity around the trunk) form the core of the preventive strategy.
- ✓ Italy: a lot of bio control (EPF & EPNs) efforts were utilized as prevention for control of RPW.

- ***Curative control measures among the G20 countries***

- ✓ Soil treatment.
- ✓ Trunk injection.
- ✓ Fumigation by aluminum phosphide.
- ✓ Wound dressing with insecticide.
- ✓ Crown drenching of infested palms with insecticides.
- ✓ Cutting the infested date palm trunks, dipping it into chemicals and then burning in specially designated places.

- ***Sustainable RPW control measures needing research attention***

- ✓ Evaluating botanical insecticides against RPWs (plant extracts, essential oils, plant secondary metabolites).
- ✓ Evaluating biological control agents against RPWs (Entomopathogenic fungi (EPF), Entomopathogenic Nematodes (EPNs), micro-encapsulation technology, using nano technology to deliver bacteria & Fungi).

- ***Summary of the future global RPW research directions***

- ✓ ***Knowledge sharing on RPW among interested G20 members for identifying***: research gaps, risk management, capacity building, technology sharing, research collaboration.
- ✓ ***Increase awareness on the destruction and threat of RPW among***: policy-makers, industry, farmers.
- ✓ ***Research collaboration***: developing dry trapping and smart trap technology, synthesis of molecular insecticides, develop RPW resistant palm varieties, augmentation of natural enemies.

Acknowledgement

This work was a part of a discussion group on integrated management practices for Red Palm Weevil during the international workshop on facilitating international research

collaboration on trans-boundary plant pests as part of G20 MACS meeting on November 27th, 2019. The contributors were Shoki Al-Dobai [2]; Elio Cesar Guzzo [3]; Giuseppe Mazza [4]; Hiraku Yoshitake [5]; Takuya Yamaji [6]; Suliman Ali Al-Khateeb [1]; Suat KAYMAK [7]; Özlem ALTINDİŞLİ [7]; Ahmed Mohammed AlJabr [1]; Ayman AlGhamdi [1]; Abid Hussain [11] Ministry of Environment, Water and Agriculture, Saudi Arabia; [2] Food and Agriculture Organization of the United Nations (FAO); [3] Brazilian Agricultural Research Corporation (Embrapa), Brazil; [4] Council for Agricultural Research and Economics (CREA), Italy; [5] National Agriculture and Food Research Organization, Japan; [6] Ministry of Agriculture, Forestry and Fisheries, Japan; [7] General Directorate of Agricultural Research and Policies/Ministry of Agriculture and Forestry, Turkey.

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Advances in Red Palm Weevil-IPM in Coconut

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Abstract

Coconut palm (*Cocous nucifera* Linn.), a versatile crop of multifaceted utilities ensures livelihood security to more than 12 million farm families in India. The Asiatic red palm weevil, *Rhynchophorus ferrugineus* Olivier, is the most fatal enemy of coconut palm spread world-wide and present in all coconut growing tracts of India. Orientation of the weevils to the palm is linked to volatiles emanating from injuries imparted by pest/disease attack or improper agricultural practices. An integrated approach covering prophylactic and curative measures amalgamated with farm and palm hygiene was developed for management of this major pest in coconut. Spot application of imidacloprid (0.02%) or indoxacarb (0.04%) or spinosad (0.013%) is effective in recovering palms from *R. ferrugineus* attack to the tune of 70-80%. Close inspection for early diagnosis, avoiding physical injuries on palm, prophylactic leaf axil treatment with pest repellent materials are essential part of IPM. Installation of pheromone traps @1 trap/ha through slow release delivery in community mode could be employed for mass trapping of the weevils. Crop habitat diversification by combatable intercrops reduced pest occurrence in palms through stimulo-deterrent strategy. Community level technology convergence and large-area adoption of IPM technologies conducted in 2150 ha in different pest-infested zones of the country reduced pest incidence by 56.8%. Refinement of early detection gadgets, gene silencing and utilization of biocontrol agents are future thrust areas for subduing red palm weevil in coconut.

Key words: Red palm weevil, Coconut, *Rhynchophorus ferrugineus, IPM*

Introduction

Coconut palm (*Cocos nucifera* Linn.) occupies a dominant role among the cultivated palm species in India as it provides livelihood securities to more than 10 million people in 18 States and 3 Union Territories of the country. The crop is cultivated in an area of 2.153 million ha with a total production of 21308 million nuts (CDB, 2020). The four Southern States *viz.*, Kerala, Tamil Nadu, Karnataka and Andhra Pradesh contribute the major share of the area (90%) and production (92%) of the crop in the country. Although production and productivity of coconut in India has grown steadily in the past few decades, occurrence of pests and diseases in majority of the coconut-growing areas in the country has considerably affected the coconut industry. Coconut palm being a perennial crop provides continuous supply of food and shelter for the build-up of various pests during all stages of its growth. Few of them are fatal or cause extensive damage to the crop as well as reduce its vigour, finally resulting in economic loss. In India, palm health management strategies in coconut were initially developed with more orientation towards the use of insecticides and fungicides, but increased awareness on the ill-effects caused by indiscriminate use of plant protection chemicals has made Integrated Pest Management (IPM) the most accepted strategy to combat pests which integrate available components in a compatible way allowing a pest residue for the natural enemies to sustain (Rajan *et al.,* 2009; Josephrajkumar *et al.,* 2018).

Distribution

Red palm weevil (RPW) (*Rhynchophorus ferrugineus* Olivier) is the most fatal enemy of coconut palm enjoying a world-wide distribution and presence in all coconut growing tracts of India. Though palms of all heights are susceptible to RPW infestation, juvenile palms are more vulnerable palms with the pest known to prefer young coconut palms (5-15 years old). Incidence of RPW is relatively high in those areas having high incidence of rhinoceros beetle, bud rot disease and leaf rot disease, which predisposes the palms to oviposition by RPW (Chandrika Mohan *et al*., 2018). *R. ferrugineus* is a major pest of date palm in Kachchh, Gujarat with distribution extending in all date palm growing regions (Muralidharan *et al.,* 2000) and oil palm plantations (Dhileepan, 1991) in India. The weevil is recently reported as emerging pest of arecanut palm especially in North Eastern Hill Region and Karnataka states of the country (Dutta *et al.,* 2010; Saneera e*t al.*, 2019).

Biology

The adult RPW is medium sized with ferruginous brown colour. Life history of RPW has been well studied and documented in many countries including India, Indonesia, Myanmar, Philippines, Iran and Spain (Nirula, 1956; Menon and Pandalai, 1960; Esteban-Duran *et al.*, 1998; Murphy and Briscoe, 1999). Several overlapping generations comprising of different stages of the insect could occur in an infested palm. The weevil takes about 3-6 months for completion of the life stages from egg to adult depending upon weather conditions and type of food source. The grubs construct an oval fibrous cocoon strongly woven, arranged spirally with pupal period ranging from 11-45 days (Menon and Pandalai, 1960; Faleiro, 2006). The adults have a prolonged life span extending up to 76 to 133 days. Laboratory rearing of RPW was attempted by many workers with natural food (coconut petiole) and sugarcane was reported as an ideal alternate laboratory host even though RPW is not a pest of sugarcane in the field. Artificial rearing was successful on semi synthetic diet (Rahalkar *et al.,* 1978; Josephrajkumar *et al.,* 2017).

Nature of damage and symptoms

Adult beetles lay eggs in the soft tissues in the cut or injured portions on the palm and the emerging grubs tunnel into the stem and feed on the tender tissues inside the palm. The weevils are attracted to the rotting smell and the pest incidence is quite severe in areas where palms are infected with bud rot disease/ leaf rot disease or infested by rhinoceros beetle. Developing stages of the pest remains hidden inside the palm for completing its life cycle. The palm is finally killed if the infestation goes unnoticed. Shallow method of planting coconut seedlings and mechanical injuries on the palms also paves way for the pest attack. Being an internal tissue feeder with all the life stages inside the palm tissues, usually the RPW infestation symptoms are ambiently visible at advanced stage of pest infestation. Yellowing and later wilting of the inner and middle whorl of leaves, small circular holes on the palm trunk with oozing out of a brown viscous fluid, longitudinal splitting of leaf base, gnawing sound of grubs and presence of cocoon/chewed up fibers at palm base are the major symptoms of RPW infestation that can be identified by close scrutiny. Severe infestation results in toppling of the crown (Nirula, 1956; Rajan and Nair, 1997). Entry of the pest through the crown is the very common in coconut and most fatal type of infestation. The grubs in such cases stay very close to the cabbage portion (growing point) of the palm and results in drying of the young heart leaves. In seedlings and younger palms entry of the pest through the bole region is generally noticed. Injuries to the soft stem due to mechanized cultivation practices are major reasons for this type of pest entry (Chandrika Mohan *et al.*, 2015).

Pest Management

- **Preventive methods**

As RPW is attracted to fresh injuries inflicted on the palms, prevention of pest incidence is possible by avoiding injuries on palm trunk and crown. It is observed that due to mechanical operations such as ploughing, cutting of steps for climbing the palms, the injured palm becomes more susceptible to weevil infestation (Abraham and Kurian, 1972). Timely treatment of wounds or injuries is indispensible to ward off pest infestation. The rhinoceros beetle visits the crown of coconut palms for feeding and RPW makes use of these palm crown injury for oviposition. Hence, prophylactic methods of pesticide application in the inner leaf axils, especially in the young palms due to their high susceptibility to pest attack is quite effective in preventing the infestation by both rhinoceros beetle and RPW. Leaf axil filling with a mixture of 250g finely powdered fresh de-oiled cake of neem (*Azadirachta indica*) or marotti (*Hydnocarpus wightianus)* along with equal volume of river sand provides adequate protection from pest attack for a period of 4 months. This method is recommended to be carried out coinciding with the peak period of adult emergence starting with pre monsoon showers in mid April–May.

Continued filling of leaf axils at 4 months interval tackles these two pests, which co-exist in the plantation (Nair *et al.,* 1997; Chandrika Mohan *et al.,* 2001). Prophylactic leaf axil filling with botanical cakes (developed from methanolic and hexane extracts of *Clerodendron infortunatum* and *Chromolena odorata*) or granular formulation of chlorantraniliprole 0.4% GR @ 3 g in perforated polythene-sachet safeguarded palms from invasion by rhinoceros beetle for 4-5 months. Placement of 10 g naphthalene balls in the inner most 3 leaf axils with sand coverings to prevent quick evaporation of the compound is also found to be effective in preventing the pest incidence in just transplanted and juvenile palms (Sadakathulla and Ramachandran, 1990). Timely fungicidal treatment for bud rot and leaf rot is also essential.

- **Habitat manipulation and cultural control**

Maintaining optimum palm density during planting is very important not only for harnessing highest benefits of light energy but also reduce the release of volatiles from the specific host plant. Spacing for tall varieties of coconut palm at 7.5 x 7.5 m and dwarf varieties 7 x 7 m is found ideal. Interspaces can be effectively used for raising intercrops so as to admix and diminish the volatile cues disorienting RPW away from host. Recommended spacing in coconut plantation also avoids chances of rubbing of fronds together during wind and thus prevents release of volatiles which in turn attract weevils for egg laying. Coconut plantations with intercrops such as fruit trees and spices were found to have lesser incidence of RPW attack than mono-cropped gardens as the intercropped system releases a bouquet of volatiles diverting the orientation of weevils away from coconut for egg laying. No RPW incidence was observed in such ecologically engineered coconut garden whereas it exceeded the action threshold of 1% in monocropped gardens. Diversity distraction of pests on the other hand could attract a wide array of pollinating foragers (bees, flies, ants) as well as defenders (entomophaga). Dwarf varieties of coconut were found relatively more susceptible to attack by RPW compared to the tall varieties. Among the dwarf cultivars, Chowghat Green Dwarf variety of coconut is highly susceptible to RPW infestation (Josephrajkumar *et al.,* 2014; 2019).

Any physical and physiological changes on the crown to bole region should be closely scrutinized to detect the pest attack in early curable stage. Avoiding physical injury to palms is very critical to reduce pest incidence. Cutting fronds leaving at least 1.2 m from trunk, avoiding knife injury on crown region during crown clearing, careful tractor ploughing moving away from the bole and frond region to avoid injuries need to be overemphasized (Abraham *et al.*, 1989).

- **Curative treatments with chemical pesticides**

Systematic diagnosis through close monitoring and vigilant scouting is the key for early diagnosis. In cases of infestation by RPW it becomes mandatory to apply chemical pesticides, either by crown application or through stem injection. Wide spectrum of pesticides has been evaluated by various research agencies including Central Research Institutes and State Agricultural Universities. Many systemic and contact insecticides have been found promising in curative treatments since 1950s. However, several promising chemicals were later banned in the country for use in agricultural ecosystems due environmental and health hazards. Among the newer pesticides evaluated imidacloprid (0.02%) or spinosad (0.013%) or indoxacarb (0.04%) were found effective in the management of RPW (Josephrajkumar *et al.*, 2014). After plugging all the holes on the lower part of the palm the insecticide solution is administered into the palm with a funnel through the uppermost hole. If the entry of the pest is through the spear leaf, cutting the highly rotten part and pouring the insecticide through the crown is recommended. In most cases young non-bearing palms are attacked by the pest. It was also found that there was no detectable residue of imidacloprid on leaves, nut and meat even after one-day after treatment up to 30 days period.

Influence of insect growth regulator, lufenuron @ 0.01% leading to defective morphogenetic moults and malformed adults may be exploited in long-term strategy in biorational approach to RPW management particularly due to the occurrence of ten larval instars for the pest (Josephrajkumar *et al.*, 2014).

- **Biological agents**

Even though many biological agents are reported from RPW, they are not very successful at field level. A highly potent cytoplasmic polyhedrosis virus (CPV), infecting all stages of RPW was recorded first in India, (Gopinadhan *et al.*, 1990). *Pseudomonas aeruginosa* (Schroeter) isolated from infected larvae collected in Kerala, India induced mortality in early-instar grubs (Banerjee and Dangar, 1995). Josephrajkumar *et al.* (2013) reported higher virulence of local entomopathogenic nematode (EPN) strain of *Heterorhabditis indica* (LC_{50} 355.5 IJ) in the suppression of *R. ferrugineus* grubs as well as greater susceptibility (82.5%) of pre-pupal stage than that of grubs. Synergistic interaction of *H. indica* (1500 IJ) with imidacloprid (0.002%) against red palm weevil grubs indicated combined application of *H. indica* infected *Galleria mellonella* cadavers and imidacloprid (0.002%) would be an effective strategy in the field level management of RPW in coconut. A new isolate of EPN (CPCRIS0804) with enhanced virulence inducing 100% mortality in RPW under laboratory with higher shelf life of more than 8 months at ambient conditions was recently reported form ICAR-CPCRI (ICAR-CPCRI, 2019). Among predators, the earwigs, *Chelisoches morio* (Fabricius) was reported as common predator of RPW eggs and larvae in the canopy of coconut plantations in India (Abraham and Kurian, 1973).

- **Attractants and semiochemicals**

Trapping the floating population of beetles was attempted by many workers. Traps of coconut logs smeared with fermenting toddy was recommended as the pest is attracted to fermenting smell. Fresh coconut logs (50 cm long and split longitudinally), cut surfaces of which are treated with fermenting toddy are placed one above the other to serve as an effective trap for RPW (Abraham and Kurian, 1975; Kurian *et al.*, 1984). With the synthesis and availability of ferrugineol based pheromone lure (4-methyl 5-nonanol (Ferrugineol) and 4-methyl 5-nonanone (Ferrugineone) for RPW, the IPM programme was modified to incorporate pheromone traps and it was successfully utilized to combat the pest in coconut and date palm (Nair and Nair, 2002, Mayilvaganan *et al.*, 2003;

Faleiro, 2006, Faleiro and Satarkar, 2003), provided all the precautionary steps involved in the use of pheromone traps are meticulously followed by the user. Installation of pheromone traps with ferrugineol embedded on nanoporous matrix @ 1 trap/ ha was found effective in mass trapping of weevils. Impregnation of kairamonal blends containing host-induced volatiles enhanced the weevil catches substantially. Slow and sustained release of pheromone blends for a period of six months was achieved in nanoporous matrix along with the reusable strategy of the matrix (Subaharan *et al.*, 2014; 2019). Timely servicing of food baits once in 6 days and avoiding traps in plantations with juvenile palms or palms intercropped with tall intercrops (banana) is recommended. Volatiles emanating from the food baits were isolated, identified and pheromone–kairomone blends were also developed by ICAR-CPCRI to use a single component in trap thus avoiding supplementation of food bait in pheromone trap.

Serine protease inhibitors *viz.*, aprotinin (50 µg), soybean trypsin inhibitor (50 µg) and phenyl methyl sulphonyl fluoride (1700 µg) inhibited the gut proteinases of *R. ferrugineus* such as trypsin, elastase-like chymotrypsin and leucine amino peptidase affecting the digestion and nutrient uptake of the insect leading to impaired growth and development (Josephrajkumar *et al.*, 2016). Use of botanical formulation with trypsin inhibition is another viable option in management of RPW.

- **Palm and farm hygiene**

Coconut palms dead due to RPW and retained in the field serve as ideal food source for second generation of the weevil acting as a source of inoculum for further buildup of the pest in the field. Hence, the importance of field sanitation needs to be properly understood by the farmers to protect the palms (Abraham and Kurian, 1972; Rajan and Nair, 1997; Josephrajkumar *et al.*, 2018).

- **Early pest detection devises**

Abraham *et al.* (1966) evaluated different aids to detect RPW infestation in coconut palm. Different methods of entry of red weevil into the palm, the important symptoms manifested by the attacked palm and the detection of the pest infestation by an electronic amplifier were studied. Ramachandran and team developed a prototype detector which could not specifically pin point the presence of grubs due to extraneous noise factor (Sivaraman *et al.* (1989). Smart detection sensors based on vibration signals of grub activity was found as a non-disruptive innovative tool for sensible early detection. In this attempt, a pattern could be decoded by the typical vibration and noises produced by the feeding grubs of red palm weevil in the lower order frequencies of 10 to 4000 hz. A time amplitude domain waveform devoid of ambient noises and persistent signals of grub feeding could be ascertained after subjecting to reverse transformation and several modes of normalization process. A prototype detector based on acoustics with >89% laboratory detection efficiency is under field evaluation trial (Josephrajkumar *et al.*, 2019).

- **Success stories on RPW management**

Integrated management technologies involving complete destruction of infested palm, close monitoring and sustained surveillance for early diagnosis, leaf axil filling with chlorantraniliprole sachet, curative management with imidacloprid (0.02%) and pheromone trap @1 trap/ha were found effective in pest suppression (Chandrika Mohan *et al.*, 2018). ICAR-CPCRI pilot tested area wide community management extension approach during 2016 as participatory action research programme involving all stakeholders. Innovative extension components such as poster campaigns, stakeholders meetings, Coconut Plant Protection and Surveillance Groups (CPPSG), operation of Integrated Coconut Field Clinics (ICFC) and intense field extension activities organized for social mobilization led to the average RPW incidence (percentage of palms) being reduced to 0.38 percent from 2.93 percent with the integrated community extension interventions. The focus on community extension with holistic farmer-participatory approach in wider area could overcome the inefficiency of individual level technology adoption and wide variation of farmers' socio-economic resource base (Anithakumari *et al.*, 2017; 2019). Community level technology convergence and large-area adoption of IPM technologies conducted in 2150 ha in Kerala (Bharanikavu, Cheppad), Tamil Nadu

(Palladam), Andhra Pradesh (Ambajipet) and Karnataka (Bidramamandi) could reduce the pest incidence by 56.8%. Palms at early stage of infestation completely recovered (80-85%) after curative treatment. Sustained surveillance, timely pest detection, sound detection awareness of the pest and perfect execution of curative management reduced the infestation level significantly. Saving approximately 1% of palms from the pest damage all over the country with complete recovery is a huge economic turnover.

Epilogue

Red palm weevil is the lethal pest of major commercial palm crops in India *viz.*, coconut, oil palm, date palm, and arecanut palm. Detailed and thorough studies on various aspects of bioecology and management have been carried out by various research agencies in the country. An IPM package consisting of prophylactic and curative treatment of palm along with palm and farm hygiene was developed and field validated. Maintaining optimal palm density supplemented with intercrops for diminishing volatile cues through crop-habitat diversification strategy reduced the pest incidence. The dispersal of RPW from traditional and nontraditional coconut cultivated areas especially in North Eastern region affects the food security of the country as the palm provides livelihood to millions of small and marginal farmers. However, in depth studies on biocontrol agents with tolerance to abiotic stress, role of plant nutrition including PGPRs, breeding for RPW resistance and development of an early pest detection device are highly essential to chalk out a cost effective, eco-friendly and sustainable management of this lethal pest. A farmer-participatory community approach of using pheromone delivery with adequate precaution would be the need of the hour to curtail the pest systematically. Practical and integrated delivery of these approaches in a compatible way including stimulo-deterrence through ecological engineering would be ideal means for the innovative management of RPW.

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Current Challenges of Red Palm Weevil Management and Impact of COVID-19 Pandemic on Global Date Palm Production

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Abstract

The red palm weevil (RPW), *Rhynchophorus ferrugineus* (Olivier) is a serious invasive insect pest of date palm and other palm species worldwide. The management strategies currently used against this pest have many gaps and challenges including the detection of infestation at an early stage, the laborious and expensive pheromone mass trapping of adults and the excessive use of chemical insecticides. Additionally, the corona virus outbreak has adversely influenced the date palm sector in general and the control efforts against RPW in particular. This article addresses the measures that could be employed to narrow the gaps in RPW management strategies and tactics as well as future prospect of global date palm sector in post COVID-19 era.

Keywords: Date palm, corona virus pandemic, management strategies, invasive species

Introduction

Dates play an important and strategic role in global food security. About 7.78 million tons of dates are produced worldwide annually. Out of this production, 88% is from the Arab world (the Gulf region, Middle East, and North Africa) (FAO, 2015). Insect pests, mites, mollusks, nematode, birds, bats and rats inflict damage and losses on date palm that are in the range of 10-30%, and even higher if timely management measures are not applied. The type and efficacy of management practices determine largely the magnitude of damage on date palm. Injuries on date palm by various pest may be on mother palms, young offshoots, immature fruits and ripe fruits in both pre-harvest and post-harvest stages (El-Shafie, 2019). Like other production sectors, date palm industry has been hit largely by COVID-19 because the sector is labor-intensive and production means depend on traditional equipment and skilled labors. It is essential to elucidate the impacts of the Corona-virus pandemic on date palm production and how to alleviate the negative effects on the production of dates. Future post COVID-19 strategies are needed to draw a clear roadmap for the sector. Sustainable pest management in date palm is considered one of the most important good agricultural practices that affect sustainable production of good quality dates. Due to the impact of COVID-19 on the date palm sector, keeping global date quality up to the standards required by the market remains a big challenge. The main objective of this paper is to highlight the crucial gaps and challenges of red palm weevil management in the date palm agroecosystem as well as the impact of COVID-19 pandemic on the production of date palm in general and red palm weevil management in particular.

Biological and ecological characteristics of red palm weevil

Several biological and ecological characteristics have made the RPW an aggressive invasive insect pest of palm species. These include, but not limited to, high reproductive potential, adaptability to different environments, a wide host range, being internal tissue borer (cryptic behavior), strong flying capacity, and aggregation behavior (survival strategy) (Faleiro, 2006; Milosavljević et al., 2019). Traits of insect pest must be taken into account when developing IPM for these pests (Zadoks and Schein, 1979). Host plant resistance is another important pillar for pest management (Kogan, 1998). RPW is considered as a serious palm killer and palm mortality may occurs within 6-7 months of the initial infestation. Larvae (broods) feed gregariously on internal palm tissues often creating large cavity in the palm trunk. RPW larvae are active feeders and larval development may takes 3-7 weeks depending on date palm variety and environmental conditions (Faleiro, 2006). The weevil may have up to three generations per annum (multivoltine), and adult weevils are relatively long-lived (months to year). All the above-mentioned characteristics have made eradication of the weevil very difficult especially after it is established in a new area.

Gaps & challenges in components of current RPW-IPM strategy

Several challenges face the implementation of the current RPW-IPM strategy, which include the early detection of infestation, pheromone trapping and data collection of weevil captures, removal of severely infested palms, slow development of new applicable field technologies, and lack of effective biological control agent (El-Shafie and Faleiro, 2020). Additional shortcomings include developing and implementing phytosanitary measures, overdependence on the use of chemical insecticide (for curative and preventive treatments), poor farmer participation in the control, scarcity of data on socio-economic issues, which calls for re-examining the entire paradigm of therapeutic approach. However, the uncertainty of palm infestation detection is a major challenge of RPW management (Sanz-Aguilar *et al.*, 2020).

The removal and safe disposal of severely infested palms is also another huge challenge (El-Shafie and Faleiro, 2020). In several countries, this aspect of the strategy is constrained by the use of costly shredding machines that need trained personnel to operate. Besides, there is the danger of the weevils escaping during transportation of the eradicated palm to the shredder outside the farm to the shredding site. In this context, Ferry (2020) recommends the processing/destruction of severely infested palms right at the farm itself. The possibility of using small portable shredders needs to be looked into. As regards chemical treatments, there is an excessive dependence on pesticide application for both preventive and curative treatments. Safe and effective methods of applying insecticide inside infested date palm need to be standardized (El-Shafie and Faleiro, 2020).

The movement of palms for new plantations or for landscaping should be highly monitored to avoid the spread of the weevil (Chouibani, 2020). RPW-risk management to reduce the likelihood of being introduced in an un-infested country should be carefully considered. In this respect, the system approach which is a combination of phytosanitary measures along the production and export chain that achieve an appropriate level of production need to be looked into (Quinlan et al., 2020). Absence of consistent protocols and certified planting materials are big challenges of RPW management strategy, beside weak enforcement of phytosanitary and regulatory rules by concerned countries is also of concern (Chouibani, 2020).

Impact of COVID-19 on Global Date Palm Production

The RPW, *Rhynchophorus ferrugineus* is an invasive devastating insect pest of date palm that has become a real threat to palm species around the globe in recent time (Milosavljević *et al.*, 2019; FAO, 2020). The date palm industry in most date palm-producing countries depends on skilled and seasonal labors to carry out almost all agricultural operations and cultural practices on the farm. Simple traditional equipment are used to perform the different farm operations including irrigation, frond pruning, pollination, thinning, bunch bagging and harvesting (Akyurt *et al.*, 2002). Other operations along the production chain including cleaning, drying, sorting, and packaging of dates in plants also require considerable workforce. The precautions adopted by almost all countries around the world to curb the spread of the corona-virus pandemic, which include complete lockdown, restriction of travel and movement; and social distancing impact seriously on the availability of field workers at a critical time in production chain. Encountering of Corona-virus disease by farmers and field workers would greatly influence workers availability to perform the different tasks on the farm. The lockdown simply means that the normal and routine work on farm is not being undertaken as required and during the specific time. Additionally, the provision of protective equipment including face masks and suitable housing facilities on farm have added tremendously to the cost of production. Furthermore, the auction markets of dates have been seriously affected by these restrictions. The management of red palm weevil includes, inter alia, the pheromone-baited traps, monitoring of the weevil populations, visual inspection of palms to detect infestation, chemical treatment of palms (preventive and curative), removal, and destruction of highly infested palms. All these operations require workers and logistics that had been affected by the pandemic. The palm crown operations including (pollination, thinning, de-thorning, frond base cutting, bagging and harvesting) are connected in one way or another with pest management. For example, thinning can drastically reduce the infestation by fruit moths and other pests. Cutting of frond bases makes the microenvironment unsuitable for the longhorn beetle, the rhinoceros beetle, and the scale insects. Bagging on the other hand, reduces the infestation by greater date moth, and sap of nitidulid beetle. Additionally, supply of farm inputs such as fertilizers (organic and synthetic), insecticides have been impacted. Work on the farm requires the physical presence of the workers (Figure 1) as work from home is not possible in case of date palm fields, unless the internet of things and robots are used.

Figure 1. A worker wearing a corona virus facemask during routine work in date palm plantation

Remote control systems could however be used for the management of irrigation operations and monitoring of insect pest using smart traps. The corona virus pandemic has also affected landmark events on date palm such as Arab date festivals to be organized by Khalifa International Award for Date Palm and Agricultural Innovation in

Sudan, Jordan, and Mauritania. These festivals, which were supposed to be held in 2020, have been postponed for 2021. Likewise, the international date palm conference, which was planned to be held during 16-19 November 2020, by the date palm research center of excellence, King Faisal University and ISHS, has been delayed to an unspecified date in 2021.

Sustainable date palm production and sustainable pest management

The main objectives of sustainable pest management (SPM) are maintaining plant health, increasing yield, and reducing crop losses. Additionally, SPM leads to sustainable environment and balanced ecosystem. SPM shares sustainable agriculture in the main four components of production, efficiency, stability, and resilience, in addition to ecological and philosophical conception (Savary *et al.*, 2012). Sustainable pest management is also concerned with the efficient utilization of resources including water, energy, labor, chemicals and genetic resources. SPM is based on the concept of total approach and it deals with agro-ecosystem as a cohesive closed system. The intervention to control insect pest in this system with therapeutic measures (e.g. application of insecticides) is a short-term unstainable solution and are usually faced and neutralized by counter moves from within the system (Flint and van den Bosch, 1981). Thus, for long-term or sustainable pest management, the inherited strengths of the ecosystem (e.g. biological control and plant resistance) should be utilized. Externalities and the use of tactics/measures should be deployed only as backup of the inherited forces of the ecosystem in suppression of pest population below levels that cause economic damage (Lewis *et al.*, 1997). Zadoks and Schein (1979) proposed the pest tetrahedron (pest, crop, environment, and human) as a modification of the disease triangle (Figure 2). The fourth apex of the tetrahedron is human resource which include, beside the farmers and growers, social networks, suppliers of agro-technologies, stakeholders, extension specialist and policy makers (Savary *et al.*, 2012). Humans greatly impact the interaction among the other three faces of the tetrahedron (the environment, pest, and crop). The environment includes the physical, chemical, and the biological component including the natural enemies of pests. The crop includes the composition of different cultivars, plant density, host resistance and crop physiology. While the pest include insects, pathogens, nematodes, weeds, and vectors of plant diseases. The four main pillars of SPM are biodiversity, host plant resistance, landscape ecology (pests, host plants, plant genotypes, trophic chain, and physical environment), and hierarchy of biological and social organizations (Savary *et al.*, 2012).

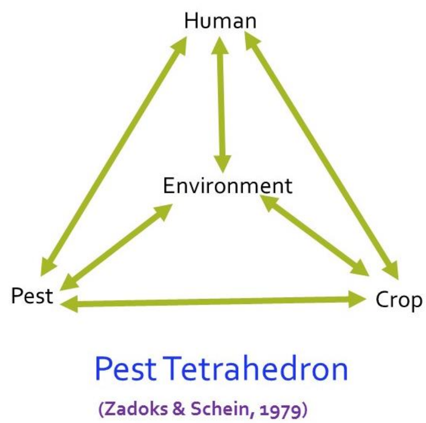

Figure 2. The interactions among components of the pest tetrahedron

The main components of sustainable pest management include identification of major pests and their natural enemies, monitoring of population dynamics of both pests and beneficial as well as the economic threshold of pests (Figure 3). Boosting date palm resistance through improved irrigation and fertilization (bottom-up effect) is an essential component of the sustainable pest management (Han *et al.*, 2019). The SPM system is evaluated according to its resilience to external factors such as invasion of insect pests, outbreak of endemic pests, socioeconomic factors such as changes in the market prices and exceptional environmental conditions and climate change.

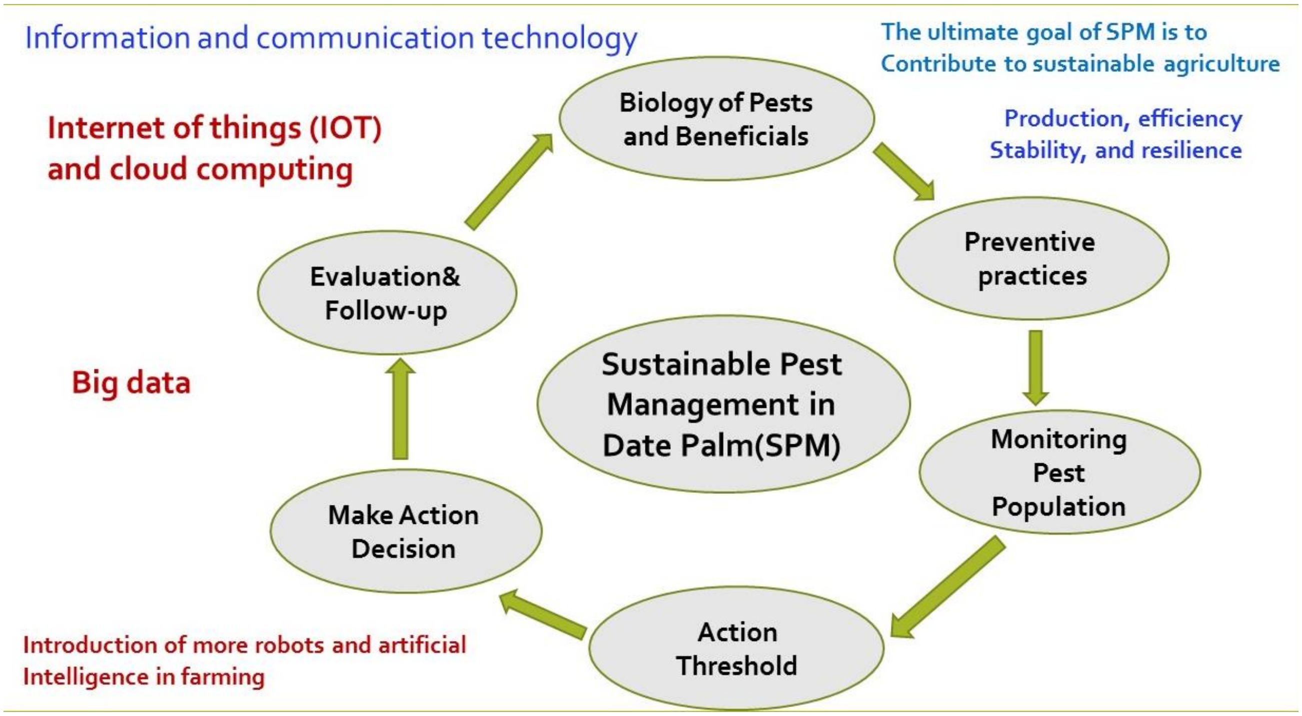

Figure 3. Components of sustainable pest management program

Prospect of the date palm sector in the post-COVID-19 era

A number of measures that should be taken to reduce the impact of COVID-19 on the date palm industry are listed below:

- The use of mechanization in all agricultural operations in the field including pest management. Sustainable ecologically based pest management should be adopted which depend largely on the biological control agents and inherited strengths of the ecosystem to suppress pest population below the economic threshold. Organic date production should also be encouraged because of its resilience that makes it adaptable to external changes including climate change and pandemic such as COVID-19.
- Cultivation of several date palm cultivars to exploit the inherent resistance among them to control major insect pests including RPW. The variation in flowering, maturation, and harvesting times of the different cultivars reduce the pressure and

demand for workers at the same time. Thus, could be one option to avoid scarcity of labor during upcoming crisis.

- Encouragement of biological control of date palm pests and development of innovative methods of monitoring and estimation of pest populations and economic thresholds. In this respect, GIS and GPs, drone and other IoT devices could be deployed on farms to collect big data, which could be analyzed and used in decision-making.
- Application of fertilizers, pesticides and other inputs could also be carried out using automated machines. Such practices would drastically reduce the dependence on hand labor and would reduce the number of workers required to perform such operations.
- Establishment of platform to organize and apply all essential agricultural practices, for example, early detection of pests, control of irrigation and fertilization using remotely controlled devices such as smart traps for detection and monitoring of the RPW and use of mobile Apps for data collection, transmission and interpretation. This could be helpful for the simple and fast identification of major pests by the farmers and growers as well as for the dissemination of essential extension information.
- Building the capacity of agricultural engineers and training and increasing awareness of farmers about the significance of good agricultural practices in sustainable date production. Framers should also be educated on how to utilize the available resources in an efficient manner.
- Adoption of area-wide approach for the management of invasive species such as the RPW and encouragement of collaboration among neighboring countries and synchronization of management efforts.
- Encouragement of applied research to generate innovative technologies that is applicable, cost-effective, environmentally friendly, and can be easily performed by the farmers.

- Reevaluation of all RPW research and support projects dealing with problem solving.
- Participatory research with farmers and adoption of citizen science would greatly contribute to solving of problems encountered in the date palm sector and its enhancement.
- Support production infrastructures including the building of mote able roads, provision of cold storage facilities and establishment of modern irrigation system.
- Establishment of farmers' cooperative societies and purchasing dates from the farmers would stabilize prices and encourage farmers to stay in the business.
- Encouragement of urban agriculture and planting of date palms in cities, villages and around houses for the dual purpose of landscaping and production of dates.
- Construction of global database on date palm and date production with open access to be a reliable free source of information on the different topics in the field of date palm.
- Exchange of information among different institutions, societies and non-governmental organizations that are concerned with date palm.
- Organization of webinars on important issues of production and protection of the date palm. Strengthening of links among universities, research centers, organizations and funding agents and coordination of research on major topics in date palm field.
- The phenomenon of big data, which is defined as massive volume of data with a wide variety, can be used in forecast and projection of different agricultural operations, support of current operational decisions and designing of different future farm activities using specific models. The use of information and communication technologies such as IoT and cloud computing in the cyber-physical farm management. This would be facilitated by introduction of more robots and artificial intelligence in date palm farming (Wolfert *et al.*, 2017).

Conclusion

Current management strategies against RPW are mainly based on monitoring and mass trapping of adult weevils using aggregation pheromones, agronomic and phytosanitary measures, chemical treatments and to less extent biological control agents. Additionally, capacity building and quarantine measures are also among the RPW-IPM components. Many gaps and challenges exist in these management strategies including early detection of infestation, optimization of pheromone-baited traps, removal of highly infested palms, excessive use of insecticides, and lack of farmers' participation in the control efforts. Successful RPW management requires more resources and effective management technologies that are adaptable to field conditions. Coordination of management operation over wide areas and the participations of farmers are essential to boost RPW control efforts. The corona virus pandemic is currently impacting on date palm industry in an unprecedented manner. The use of machine, robots, artificial intelligence and being able to remotely carry out some of the on-farm operations would represent an important alternative to alleviate the impact of COVID-19 outbreak on date palm sector.

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Another Conception of the "Preventive" and "Curative" Treatments to Control the Red Palm Weevil

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Abstract

The usual conception of "preventive" and "curative" treatments leads to extremely rare assessment of these treatments as components of IPM strategy although this strategy is systematically recommended as the right one to control the Red Palm Weevil **(**RPW), *Rhynchophorus ferrugineus* (Olivier). In addition to the lack of scientific results on the efficiency of these treatments in real field conditions, the usual way to assess this efficiency does not integrate the fact that it depends on the efficiency of each component of the strategy (strong interdependence). Furthermore, it presents the risk to miss out the essentials to assess the efficiency of the RPW control programmes and even to misconceive what should be the objective of these programmess.

The objective of the RPW control programmes, as in fact of any IPM programme when the economic threshold is exceeded should be to obtain the quick decline of the pest. In case of RPW it is largely exceeded everywhere in the world. Two indicators allow perfectly to determine if this decline is or not strongly represented *viz.* the evolution of the number of new infested palms and of RPW captures in the traps during successive periods of time.

Monitoring carefully and permanently these indicators is indispensable to assess if globally all the components of the integrated strategy are efficient. This information is especially indispensable at the local level where action takes place. It should be easily accessible to each group of neighboring palms owners. It would facilitate their participation to RPW control programme. A greater contribution of their part in the

implementation of the various components of the strategy would considerably increase its technical and economic efficiency. For this purpose, a version of the *SusaHamra* system, developed by FAO and simplified for an exploitation focused to the registration and easy analysis by the local field actors, especially the farmers groups, of the two indicators mentioned above would be of great help.

To contribute to the shift of conception of the “preventive” treatment and the “curative” treatment, I propose, for a better evaluation of these two components of the integrated strategy of the RPW control programmes, to call them respectively “reproduction preventive” treatments (prevention of oviposition) and “sanitation” treatments (eradication of RPW in infested palms, including when necessary palm eradication). Presently, data are totally missing to evaluate the contribution of each component of the integrated strategy to the reduction of the RPW population (represented by the reduction of the number of new infested palms in successive periods of time). It would be very useful that, at least at experimental field level, studies on that issue be engaged.

Key words: *Rhynchophorus ferrugineus*, Integrated Pest Management, Red Palm Weevil control programme, farmers participation, economic threshold, sustainability, treatment efficiency, treatment persistency, quarantine pest, GIS, eradication.

Introduction

Within the last 35 years, the Red Palm Weevil (RPW) *Rhynchophorus ferrugineus* (Olivier) has been introduced, due to palms trade, in a considerable number of countries, especially in all the Near East and North Africa countries, except Sudan and Algeria, and in all the countries of the Southern Europe and of the Eastern Mediterranean region.

In the infested countries, it has also been spread rapidly everywhere within the country, essentially as a consequence of the trade of palms or offshoots but also ornamental palms, initially infested by the imported palms (Ferry, 2019a). At its origin, this catastrophe is the consequence of the absence or the deficiency of quarantine measures, including the production of phytosanitary certificates and implementation of inspections deficient for technical value (Ferry and Gomez, 2013).

In very few infested countries, the RPW control programmes have allowed to eradicate the pest (Fajardo *et al.*, 2019). In some oasis, eradication or important reduction of the pest has been obtained but re-introduction of new infested palms has reduced to zero these successes (Ferry, 2019a). Presently, in most of the countries, the natural spread of RPW to the palms around the infested palms is very active, in addition to the occurrence of new spots of infestation due to the internal trade of palms and sometimes to the continuation of palms imports from infested countries. In some countries, it is considered that the prevalence of infested palms is low but this statement is not well founded and this result is obtained thanks to high public resources, in unsustainable conditions in the medium and long term (Ferry, 2019a), both for economic reasons (high endless cost) and for environmental/health reasons (Abbassy *et al.*, 2017).

Nevertheless, since 1998, the strategy and the techniques to control this pest on date palm in oasis was established (Abraham *et al.,* 1998) and confirmed (Faleiro, 2006). The situation is similar regarding the control of the RPW on ornamental palms in urban environment (Ferry and Gomez, 2008).

Treatments that are named “preventive” and “curative” constitute two components of this strategy. The knowledge about the efficiency of these treatments, especially regarding the preventive ones for date palms and in hot arid environment, is still insufficient in real field conditions and even in field experimental conditions. However, there is no doubt that these treatments when well applied and for which enough experimental rigorous field results are available, present a certain interest. It justifies their use as long as they are applied as components of an IPM strategy whose objectives are clearly established and as long as they are not proposed to be applied indefinitely.

These treatments are usually only conceived, implemented and assessed for their efficiency to protect the palms or to cure the infested ones. They are not evaluated for their conformity with the principles of IPM. More globally, they are not evaluated as components whose usefulness depends strongly of the implementation and efficiency of the other components of RPW integrated control strategy. The “preventive” and “curative” treatments, as each component of such strategy, should be conceived, implemented and evaluated taking into consideration that the strategy has to be implemented in the whole infested area with the objective to reduce the pest population in a sustainable way, which means rapidly and strongly.

To integrate these aspects, I propose in this paper another conception of the “preventive” and “curative” treatments, different to the usual one and that should allow to better conceive and monitor the RPW control programmes. In order to better mark this difference in conception and objective of these treatments, I have called in this paper the “preventive” and “curative” treatments respectively “preventive reproduction treatment” (prevention of oviposition) and “sanitation treatment” (eradication of all forms of RPW in infested palm, including when necessary palm eradication).

Assessment of the usual conception of the “preventive” treatments

General assessment

Preventive treatments are often recommended without being based on results of rigorous experimental field work to evaluate their efficiency and the duration of their residual effect (persistency).

Regarding experimentation results, most papers published on these treatments consists of evaluating the effect of insecticides on adults or larvae in laboratory conditions. The corresponding results are useful but not sufficient to evaluate the efficiency of such treatments in field conditions.

Papers in small number have also been published where these treatments, especially for date palms and in hot arid conditions, were tested in field experimental conditions. In that case, most of the protocols used to evaluate the efficiency were based on active substance residue analysis. However, it has been established that this kind of protocol can lead to erroneous conclusions as the active substance can be metabolized in another molecule as active or even more active than the original active substance against the pest. This result was clearly demonstrated especially with thiametoxam (Gómez *et al.,* 2011). For many insecticides, the metabolites of original active substance are even unknown. To evaluate the efficiency of treatments, protocols based on bioassays with larvae allow avoiding this problem (Ferry and Gomez, 2014) but very few papers are based on such protocols.

One of the reasons why experimentally robust results on the efficiency of spraying or soaking treatments in experimental field conditions are not numerous is that the protocols are complex and difficult to implement because it is usually not possible to dispose of homogeneous infested plots and it is of course not possible to release adults. For "preventive" treatments by injection, the experimentation is much easier and part of the available results is based on robust experimentation protocols.

Finally, to my knowledge, in only one paper, this type of treatments has been evaluated in real field conditions as a component of IPM strategy and for their contribution to control the pest inside an integrated control programme aimed to obtain the RPW regression. (Ferry *et al.*, 2019).

The main problem regarding preventive treatments is not the lack of efficient insecticides but the implementation of right application methods to reach the adults, the cost of treatments and the health and environment risks (Ferry, 2019b).

Soaking versus Spraying

It is not rare to see that today the classical way to apply phytosanitary treatments by spraying the insecticide solution is still used in the case of RPW. The efficiency of such mode of application is low because it does not answer the objectives of such treatments: to reach the adults and to extend as much as possible the effect of the treatment to protect the palms from new infestation.

The adults spend most of their life hidden at the petioles and leaves bases where they feed (mainly drink) by digging small holes and that constitutes also the main site of oviposition of the females. It is in that region that the insecticide solution must reach. It is useless to treat the whole foliage or trunks of old palms (except when fresh wounds or aerial roots are present).

In palms, the base of each frond petiole is covered by fibrous leaf sheath (fibrillum / lif) of various other leaves. This fibrous matting corresponds to the dry part of leaf sheaths and constitutes a tissue that will absorb the insecticide solution. In addition, the very shape of the petiole base creates a small reservoir where insecticide solution can be retained and will pass from petioles bases to lower ones as the reservoirs are filled. These two advantages will be much better exploited if the insecticide solution is applied by soaking the petioles bases, instead of being sprayed. Even if soaking is well applied it requires a bit more time than spraying, this disadvantage is largely compensated by the treatment efficiency, especially for its extended effect and also its capacity to reach through the oviposition holes the eggs and the early stage larvae. To soak correctly with classical spraying equipment, the nozzle of the sprayers must be removed.

Since at least 1998 (Abraham *et al.*, 1998), the interest of applying soaking treatments instead of spraying treatments was recommended.

Another great advantage of such way to apply the treatments is also to prevent or reduce greatly the dispersion of insecticides in the environment and consequently to reduce health risk for the workers and soil and water contamination.

Targeting the treatments to the oviposition sites

Because of persistent and surprising misconception, it is still often stated that wounds are necessary for RPW oviposition. However, since at least 1911 (Gosh, 1911), it was established that previous wounds were not necessary for oviposition and that female dig holes in which they lay their eggs. Various authors have confirmed this information (Wattanapongsiri, 1966; Ferry and Gomez 2011; Ince *et al.*, 2011). The extraordinary ballet that female realize to lay their eggs have also been described (Ferry and Gomez, 2015).

The behavior of the female for oviposition has fundamental consequences. The depth of oviposition holes is strictly limited to the length of the rostrum till the antennae. As the eggs must be imperatively placed in living tissues for their survival as well as for the survival of the first instars stages and as the female realizes oviposition in hidden places (except in the presence of fresh wounds), the sites of oviposition are very specific (Ferry, 2019). These sites must be the targeted sites of the treatments.

Unfortunately, because this behavior for oviposition is still ignored, it is frequent to find, even in recent scientific papers, that the sites of oviposition are: wounds, cracks and crevices, wound pruned rachis, junction between mother palm and offshoots, places like the trunk base (where in fact they just hide) or old remaining petioles where the superficial tissue is necrotic at a depth much superior to the rostrum length, etc. Only fresh wounds and of sufficient size constitute possible oviposition sites. Otherwise females can be attracted by volatiles resulting of a wound but the wound by itself, if its size is not sufficient for the oviposition ballet to take place, will not constitute oviposition site. For oviposition, females don't need previous wound. Females dig exploratory holes before oviposition; they will not lay their eggs in drying or dry wounds. In addition, for date palm, at the difference of what occurs for coconut or *Phoenix canariensis* for example, palms of more than 2-3 meters trunk height and without offshoots are rarely infested (excepted when they present a wound of sufficient size or live aerial roots). When infestation occurs in a date palm of more than 3 meters, it is usually with male palm and infestation takes place at the crown level like with coconut and *Phoenix canariensis*.

Because of the misconception on oviposition, the right way to apply "preventive" treatments is still often misunderstood. Preventive treatments should be applied essentially on date palms of less than 2-3 meters trunk height and targeted to the sites of infestation that are also the places where the adults are hiding most of the time: the offshoots, the trunk to soak the base and the remaining petioles and the crown fronds bases.

Persistency of the efficiency

In very few experimental papers, the persistency of action of «preventive» treatments by spraying or soaking has been established. The situation is similar for chemical and biological treatments.

For spraying or soaking treatments, a certain efficacy can be obtained if the formulation is liquid and the application is repeated each 2 to 4 weeks and well targeted to the base of the petioles where chemical insecticides or biological agents are protected from the direct sun effects.

Systemic insecticides for soaking treatment

Amongst the insecticides that are used for spraying or soaking treatments, some of them are recommended because they are known to be systemic. This reason is not valid because the leaves of the palms are covered by a thick cuticle that prevents nearly totally the absorption of the insecticide. A bioassay with imidacloprid and thiametoxam allowed to confirm this point (Gómez *et al.*, 2011). The systemic insecticides act essentially by contact in the case of these treatments.

Injection

Preventive treatments by injection have been used at large scale on *Phoenix canariensis* in Europe. In contrast with the soaking treatments, strong experimental protocols based on bioassays can be used to assess the efficiency and the persistency of such treatments in the field. Very low cost, easy to use and safe techniques, especially when injection is based on infusion mechanism, are available.

One of the main problems of this technique is the production of wounds resulting of the hole done to inject the insecticide. To limit the mechanical and physiological risks that can result from the production of numerous injections, these must be well separated and also be as shallow as possible (15 cm depth maximum in the trunk after passing the remaining petioles).

In the use of this technique for ornamental palms, long persistency insecticides are preferable to limit the number of injection and to reduce the cost. For palms cultivated for fruit production, injection can also be done but taking into account a delay before harvest (variable with insecticide type) to prevent the presence of insecticide residues in the fruits.

Conclusion

The knowledge on the effectiveness in the field of the «preventive» treatments by soaking chemical or biological products as well as the duration of their residual effect is still insufficient. Nevertheless, it can be concluded from the available experimental data that, even if their effectiveness, especially in the case of date palms and in dry arid environment present certain limits (short persistency), they can play a role as a component of an IPM approach if they are well applied as described above and repeated frequently.

Assessment of the usual conception of the "curative" treatments

Curative treatments by heavy soaking the infested zone with chemical insecticides or nematodes can be effective if they are applied frequently and during sufficient time to prevent the reproduction of the weevil (by killing the RPW in cocoons that are in contact with the outside). Curative treatments with *Beauveria bassiana* strains that have been tested cannot work because endophytic migration that in addition requires previous injection, is limited to a very small zone (Gómez *et al.*, 2009).

Curative treatments are done by injection of chemical insecticides for many years and their efficiency is high when well applied (Abraham *et al.*, 1998). As already mentioned very simple and low-cost methods (a simple syringe or tube can be sufficient if the insecticide can be injected a little or no diluted) can be used.

Nevertheless, alternative mechanical sanitation methods exist. They can be easily applied by the farmers themselves (Ferry, 2020).

Fumigation with phosphine although it is applied in some places is a risky technique that should be applied only by specialized staff. The use of such technique in the field is forbidden in many countries. It is only authorized in special chambers. For these reasons and because alternatives exist, the interest of this technique is very limited.

Another conception of the "preventive" and "curative" treatments

In this conception, «preventive» and "curative" treatments are conceived, implemented and assessed as inseparable components of IPM programmes to control a quarantine pest. The objective of such programmes in the case of the RPW that is a deadly quarantine pest is to obtain quickly the decline of the pest and possibly its eradication.

In this framework, the objective of the «preventive» and «curative» treatments is much more ambitious than those addressed in the usual conception of these treatments.

The objective of the «preventive» treatments is not to protect the palms but to kill the adults and to prevent oviposition or even to kill eggs and larvae at the first stage when they are still close to the surface. The objective of the «curative» treatments is not to cure the palms but to eradicate all the weevils present in the infested palms (when possible by preserving the infested palm) and consequently to eradicate spots of RPW reproduction and spreading.

In the framework of this conception, the objective of the «preventive» and «curative» treatments is to contribute in strong interrelation with other components of an integrated strategy to obtain the quick reduction of the RPW population. Consequently, it will be in view of this objective that they will have to be conceived, implemented and assessed. I would like to underline that this conception presents the great advantage to conceive and assess the treatments not individually as it is done in the usual conception but as components which efficiency depends of the effectiveness of each of the other components.

To contribute to the shift of conception of the "preventive" treatment and "curative" treatment, I propose, for a better evaluation of these two components of the integrated strategy of the RPW control programmes, to call them respectively “reproduction preventive” treatments (prevention of oviposition) and “sanitation” treatments (eradication of RPW in infested palms, including when necessary palm eradication).

Conception based on IPM approach principles

The two fundamental pillars of the IPM approach are:

- to avoid or to limit as much as possible the use of synthetic chemical products, because of the risks that they could present for environment and health, by implementing other methods of control (including, as a priority, the prevention of the pest introduction). Nevertheless, as the RPW is a quarantine pest, it may be considered acceptable to qualify this principle if the effectiveness of a chemical “preventive reproduction treatment” is much greater than that of the other components of the IPM strategy and its use would result in a rapid decline of the RPW. In this case, it would be legitimate to give preference to a chemical treatment, taking into account that its use would be limited to a short period of time. Unfortunately, chemical “preventive” and «curative» treatments have been applied in many places for tens of year resulting in hazards for health and environment.

- to take into consideration two economic thresholds in order to establish from which level of pest population, control programme has to be implemented and from which level the cost of damages becomes superior to the cost of control. In the case of the RPW, that is a pest that first kills very quickly and unavoidably the palms that it has infested if nothing is done to prevent it and, secondly, reproduces rapidly and intensively in the infested palms, it must be considered that the economic threshold is reached as soon as one infested palm is detected and even before if a pest free area is located closed to an infested one. Regarding the economic injury level (EIL), data are missing to establish it. The situation is especially problematic in the places where the cost of the control is entirely funded by of the State and/or where the date palm cultivation is now much more based on cultural than economic reasons. In these places, the incidence of infestation is far beyond the EIL for many years.

In view of the two principles of IPM mentioned above should lead to reconsider in many places the conception of RPW control programmes and of the "preventive" and "curative" treatments in these programmes.

An IPM programme targeting the quick decline of the RPW

The different components of an IPM programme targeting the quick decline of the RPW and their interrelation are schematized in figure 1.

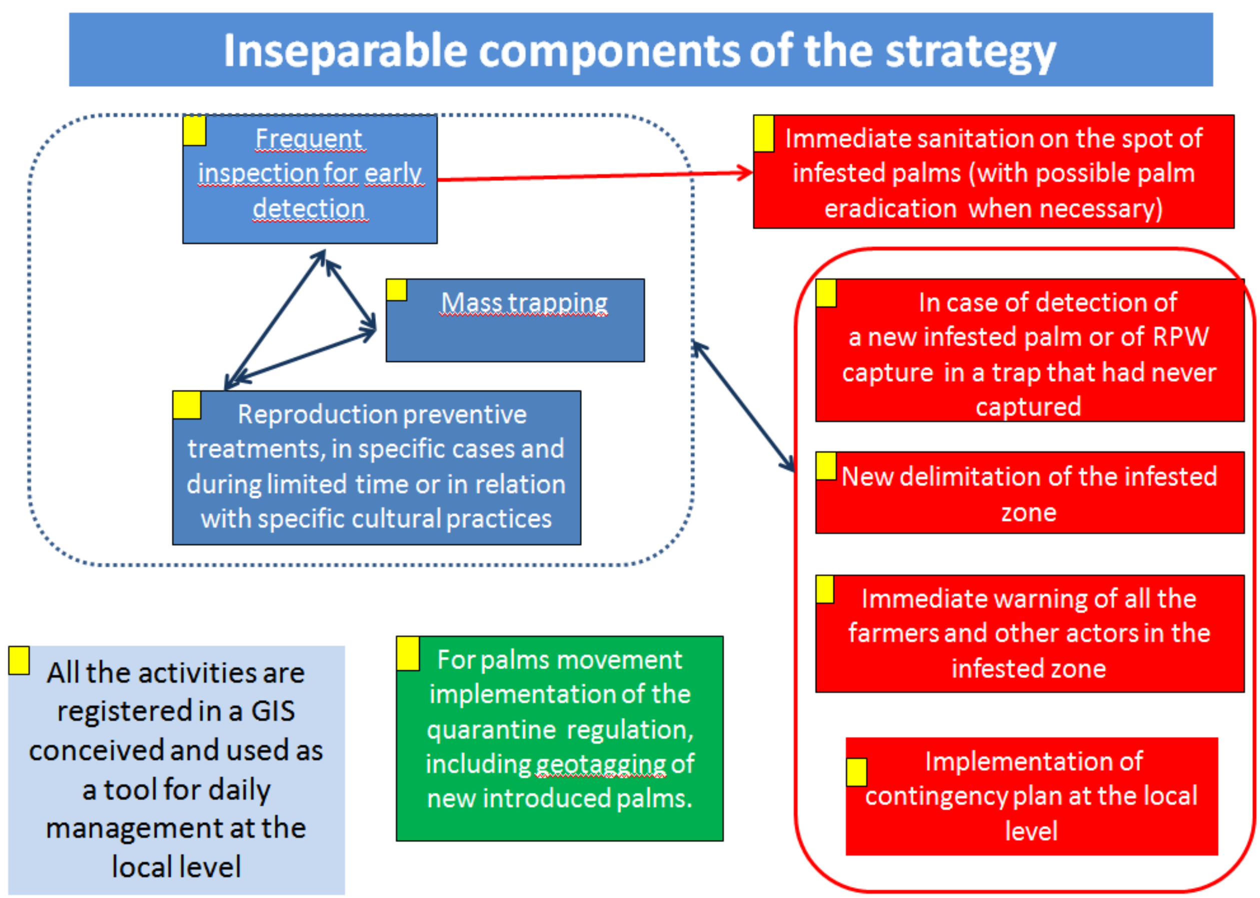

Figure 1. Integrated strategy to obtain the quick decline of the RPW

Two conditions are necessary to assure the success of such strategy:

- it must be implemented in the entire potentially infested area, considered as the zone where RPW is present at a given time, including the infested palms and the not yet detected infested palms. The exact limits of this zone are of course is impossible to establish. For practical and economic reasons and because the natural spread of RPW is aggregative/clumped around the infested palms, the potentially infested area corresponds to the zone where at a given time are present the infested palms and the traps that capture, increased by a strip of few hundred meters. Implementing the strategy only in some places of this zone is doomed to fail because the control of the pest in these places become rapidly unsustainable if RPW continue to reproduce in uncontrolled infested palms located around these places.

- all the activities and the results must be registered (with their geo-tagging) and updated permanently (GIS) to monitor the right implementation of the strategy and to react rapidly if the results don't correspond to what was expected. This tool is also indispensable for the exchanges with and between the palms owners and for early warning.

Reproduction preventive and sanitation treatments integrated inside a global strategy

The different components of the strategy must be applied in a very complementary way to assure the best efficiency of each of them and of the global strategy. It must be noted that no data so far have been published to establish the contribution of each component of the strategy in the efficiency of the global strategy. It is not easy to address this question but it would be very interesting that it is studied, at least at an experimental scale.

Although theoretically, the different components of this strategy or at least some of them could allow when applied alone to control the pest, such result would be difficult to obtain in real field conditions at the scale of a large potentially infested area.

Sanitation treatments usefulness depends of the inspection efficiency

Sanitation treatments if applied before new adults emerge and spread would allow as unique component of a strategy prevent the reproduction of the RPW and would lead rapidly to the eradication of the pest. However, although visual and by touch inspections when they are realized frequently allow to detect infestation early, the efficiency of inspections will not be sufficient in real field conditions and at a large scale to detect on time all the infested palms and so sanitation treatment alone cannot permit to control the pest. Nevertheless, inspection followed by immediate sanitation when an infested palm is detected contributes undoubtedly to the efficiency of the global strategy. Leaving infested palms without acting for months or even till they dry makes much more difficult to obtain the quick regression of the pest. Much more difficult but not impossible because it is important to repeat, that when a palm is finally killed by the RPW, it ceases to be a problem.

Furthermore, it is important to underline that in the framework of the conception of the sanitation treatments proposed in this paper, their efficiency, even if sanitation (RPW eradication in an infested palms) can perfectly be efficient at 100%, depends very much of the efficiency of the inspection component of the global strategy. When detected and sanitized late, an infested palm will have released part of the RPW population that it contained. In that case, the usefulness of the sanitation will be inferior.

It must be added that inspection and sanitation, especially if it is mechanical, could be perfectly implemented by the farmers themselves after training.

Reproduction preventive treatments usefulness and complementarily with the other components of the strategy

At a small scale, "reproduction preventive" treatments applied rigorously (mode of application, frequency) could allow as unique component of a strategy to obtain the rapid decline of the pest and finally its eradication. Modelling and results obtained at a medium scale have even allowed to establish that if only 75% of the palms of an infested zone were treated with a technique, at the same time, very efficient and affordable for the majority of the palms owners, the quick decline of the RPW population could be obtained in four years (Ferry *et al.*, 2019).

Nevertheless, such results could most probably not be obtained at a large scale in palms plantation for fruit production because, first, the technique mentioned above is only acceptable for ornamental palms (no problem of residue in fruits) and, secondly, the implementation at a large scale of soaking treatments that have to be repeated each 3-4 weeks to be efficient seems unrealistic even if applied during only few years. However, reproduction preventive treatments can contribute to the decline of the RPW population and consequently to the success of the global strategy if they are applied in specific cases and for a short period of time: new or small spot of infestation, hot spot of infestation (traps capturing a lot, infested palms detected late), on the palms in the vicinity of traps, after offshoots removal, pruning or mechanical sanitation.

Regarding these three last cases, I would like to insist of the importance to change the perspective: the implementation of these cultural practices, that anyway are indispensable, has usually perceived as problematic because they lead to the production of wounds kairomones that could attract RPW and facilitate the female oviposition. First of all, no data (at the contrary it is well established that the largest part of adults remains in the infested palms as long as possible) demonstrate that wound kairomone could contribute to increase the number of RPW that will leave an infested palm. The main effect of wound kairomone will be that the wounded palms will be more attractive than the no wounded palms. Secondly, wounds to become a favourable oviposition site needs to be of a sufficient size. Consequently, wound kairomone emission (that is, in addition, of short duration) is not so problematic and on the contrary the attraction that they produced should be used as deadly traps for the RPW thanks to the implementation of "reproduction preventive" treatments on wounded palms.

Mass trapping and interconnection with the other components of the strategy

At the difference of the two other components, it is known that mass trapping as unique component of a strategy will not be sufficient to control the RPW. The increase of the number of traps, even if it was practically and economically feasible, present limits as traps interference would lead to counterproductive effects. In real field condition and even in experimental field condition, the percentage of RPW population that the best trapping system can capture has not been established. Nevertheless, it is estimated not to be more than 50%. A recent result (El-Shafie and Faleiro, 2017), although obtained in specific laboratory conditions, gives even a lower figure.

Nevertheless, mass trapping constitutes an essential component, complementary of the other components of the global strategy not only for its contribution to reduce the RPW moving adults population, especially the female one, but also for its monitoring role. The evolution of the captures in the traps will help to improve or to modify the implementation of the other components: intensification of the inspections around traps where captures do not decrease and reproduction preventive treatments around traps that capture a lot besides, increasing the number of traps in hot spots of infestation.

The advantage of mass trapping, in addition to be an ecological technique of control, is that low cost traps can be perfectly manufactured and managed by the palm owners themselves.

Assessment of the usefulness of different components of the global strategy, including the reproduction preventive and «sanitation» treatments

As already mentioned, the contribution of each component of the global strategy, including «reproduction preventive» and sanitation treatment, to the efficiency of the strategy is not easy to establish.

Nevertheless, this contribution can be assessed qualitatively. For example: inspection is not well done if infested palms are detected late or if traps capture and infested palms are not found in the vicinity of the traps; when reproduction preventive treatments have no effect on traps captures reduction or decrease of new infested palms, it can mean that they are not well applied; etc.

In addition, two excellent indicators allow assessing the efficient of the global strategy and at least the jointed efficiency of its components: the evolution of the number of new infested palms and of traps captures during successive periods of time.

I would like to emphasize one fundamental point regarding the indicator on infested palms. In reports and papers, it is not rare to find data concerning infested palms without any reference to period of time, as if an infested palm remained infested indefinitely. An infested palm will be sanitized, eradicated or will die rapidly. At that moment, it can no longer be considered as infested palm and consequently as a focus of RPW reproduction and spread. So it is absolutely indispensable to associate the number of infested palms to a period of time (as well as with the indicator “incidence” or with the “reproduction number”). To avoid any confusion, it is better to use the expression ‘new infested palms’ because it leads automatically to complete with a period of time. In addition, what matters is the evolution of this number in successive periods of time and it is not this number by itself.

If the different components of the strategy including the reproduction preventive and sanitation treatments are well applied, the number of new infested palms and traps captures must decrease rapidly during successive periods of time. As illustrated in the following figures, the quick decline has been perfectly obtained in the framework of the RPW control in the Canary Islands.

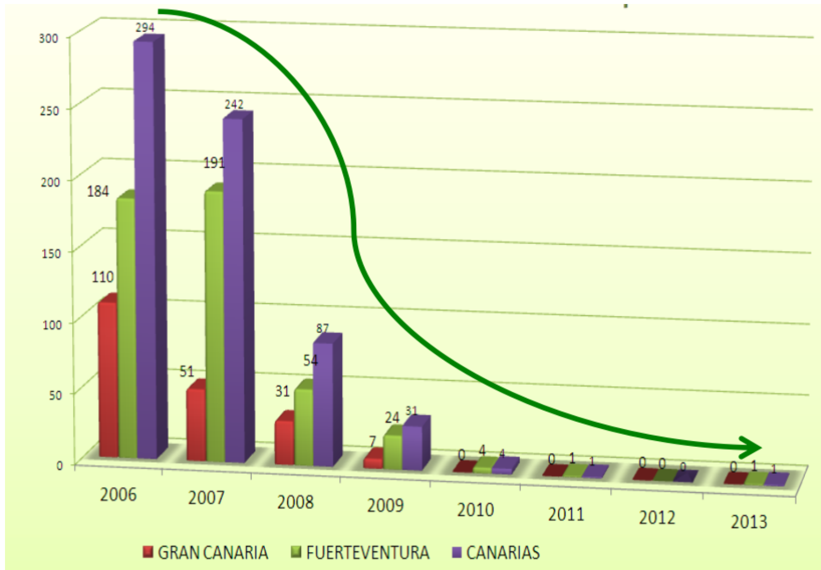

Figure 2: Evolution of the number of new infested palms per year in each island from 2006 to 2013 (Source: Fajardo *et al.*, 2019)

To assess the jointed efficiency the different components of the strategy, including the reproduction preventive and sanitation treatments, it is necessary to register the detection of each new infested palm and of the action that has been taken to sanitize it as well as the results of the periodic inspection of the traps. These data must be transmitted, computerized and integrated in a data base to be analyzed easily and at any moment with the help of a GIS programme. To have this information update permanently and easily available to all the actors at the local level, especially the farmers groups, is absolutely fundamental because it is at this level that action takes place (early warning, exchanges between palms owners, contingency plan implementation).

Unfortunately, in very few places, these data are available or exploitable in an easy way. Consequently, this essential tool to monitor permanently and easily the situation and the organization of the RPW control programmes at the local level is missing. This gap is probably one of the more serious one of the RPW control programmes worldwide. The persons in charge of the RPW control programme in Canary Islands consider that the management with the assistance of a GIS was a key element of the success of this programme (Fajardo *et al.*, 2019).

Recently FAO has developed a complete system, from data registration in the field with smartphone (*SusaHamra* app) to GIS-based online platform for data analysis and mapping (Cressman, 2019). A simplified version of this system that would include only the two main indicators that import for monitoring the implementing the RPW control programme, detection of new infested palms and captures in the trap, could be of enormous interest to improve the efficiency of these programmes at the local level. It could also greatly contribute to facilitate the participation of the farmers to the implementation of the different components of the RPW control programmes. Increasing this participation is absolutely essential as it was underlined during the Rome meeting in 2017 (Faleiro *et al.*, 2019).

Conclusions

The usual conception of "preventive" and "curative" treatments leads to extremely rare assessment of these treatments as components of IPM strategy although this strategy is systematically recommended as the right one to control the RPW. In addition to the lack of scientific results on the efficiency of these treatments in real field conditions, the usual way to assess this efficiency does not integrate the fact that it depends on the efficiency of each component of the strategy (strong interdependence). Furthermore, it presents the risk to miss out the essentials to assess the efficiency of the RPW control programmes and even to misconceive what should be the objective of these programmes.

The objective of the RPW control programmes, as in fact of any IPM programme when the economic threshold is exceeded should be to obtain the quick decline of the pest. In case of RPW it is largely exceeded everywhere in the world. Two indicators allow perfectly determining if this decline is or not strongly represented *viz.* the evolution of the number of new infested palms and of RPW captures in the traps during successive periods of time.

Monitoring carefully and permanently these indicators is indispensable to assess if globally all the components of the integrated strategy are efficient. This information is especially indispensable at the local level where action takes place. It should be easily accessible to each group of neighboring palms owners. It would facilitate the participation of the local communities in the RPW control programme. A greater contribution on their part in the implementation of the various components of the strategy would considerably increase its technical and economic efficiency. For this purpose, a version of the *SusaHamra* system, developed by FAO, and simplified for exploitation focused to the registration and easy analysis by the local field actors, especially the farmers groups, of the two indicators mentioned above would be of great help.

To contribute to the shift of conception of the “preventive” treatment and “curative” treatment, I propose, for a better evaluation of these two components of the integrated strategy of the RPW control programmes, to call them respectively “reproduction preventive” treatments (prevention of oviposition) and “sanitation” treatments (eradication of RPW in infested palms, including when necessary palm eradication). Presently, data are totally missing to evaluate the contribution of each component of the integrated strategy to the reduction of the RPW population (represented by the reduction of the number of new infested palms in successive periods of time). It would be very useful that, at least at experimental field level, studies on that issue be engaged.

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Evolving Trends in Semiochemical Mediated Technologies against Red Palm Weevil

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Abstract

Semiochemical mediated technologies targeting the Red Palm Weevil (RPW) *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae), have been practiced for over 100 years and mainly revolve around attracting and capturing adult weevils. Early work on this aspect ranges from the use of fermented kitual palm *Caryota urens*, to the use of malt extract and iso-amyl acetate as good attractants to trap *Rhynchophorus* weevils. This subsequently evolved into the use food attractants in coconut plantations to capture RPW adults during the 1970s-1980s. The landmark discovery and synthesis of the male produced aggregation sex pheromone (ferrugineol) in 1993 gave a new dimension to RPW trapping which led to the use of food baited RPW pheromone traps in large scale monitoring and mass trapping programs. Post 2010 dry trapping techniques against RPW in the form of the Electrap^{TM} and attract and kill technologies were reported. Further, smart traps involving automatic recording of weevils trapped to the GIS aided *Susahamra* App developed by FAO for data collection and interpretation are recent advancements aiding in RPW trapping programs. Though there is the possibility of deploying 'attract and infect' technique against RPW and also using insect repellents to protect palm injuries and in push-pull strategies, these techniques need further testing.

Key words: *Rhynchophorus ferrugineus* (Olivier), palms, IPM, semiochemicals

Introduction

The Red Palm Weevil (RPW) *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae) also known as the Asian Palm Weevil is a key pest of palms (Arecaceae) in diverse agro-ecosystems the world over. Globally RPW is being reported from nearly 50 countries (EPPO, 2020) with a host range of 40 palm species (Anonymous, 2013). The spread of RPW has been rapid after it gained entry into the Middle-East and was reported on date palm from UAE during 1985. Large scale movement of planting material both for farming and ornamental gardening have contributed to the quick spread of the RPW during the last three decades (FAO,2017).

Infestation begins when gravid female weevils lay eggs into palm tissue that hatch into damage inflicting larvae which bore and tunnel the palm. The hidden/cryptic nature of the pest makes detection of infested palms extremely difficult (Abraham *et al.*, 1998; Faleiro, 2006). In case of coconut and date palm infested palms have to be detected through regular visual observations of individual palms in the susceptible age group of less than 20 years (Abraham *et al.*, 1998). In the canary island palm which is the most preferred host of RPW infestation usually occurs in the crown, making detection even more difficult (Jaques, 2020).

During March, 2017 the Food and Agriculture Organization of the UN organized a 'Scientific and High-Level Meeting on the Management of RPW' and through the 'Rome Declaration' called for the urgent need to combat RPW by collaborative efforts and commitments at the country, regional and global levels to stop the spread of this devastating pest (FAO, 2019).

There exist gaps and challenges in almost all the components of the current RPW-IPM strategy (Faleiro, *et al.*, 2018; El-Shafie and Faleiro, 2020). Although, there are several research publications and ongoing research programs on RPW in many countries, there is an urgent need to further intensify RPW research to develop user friendly technologies including those related semiochemical techniques. In this context, FAO has recently launched a diverse research program on RPW for the Near East and North Africa (NENA) region. Semiochemical mediated control of RPW is currently confined to the use of food baited pheromone traps in monitoring and mass trapping programs (Soroker *et al.*, 2015; Oehchlager, 2016). This paper gives an overview of the evolution in semiochemical mediated technologies against RPW over the years.

Semiochemical mediated technologies against RPW: Overview

Early work:

The use of attractants to capture RPW adults goes back to over 100 years. Henry, 1917 first suggested that fermenting kitual palm (*Caryota urens)* stem could be effective in trapping adults of RPW. Later, Haglay, 1965 reported that a mixture of malt extract and iso-amyl acetate is a good attractant to trap weevils of *R. palmarum*. This mixture was also found to attract adults of RPW in India.

Food baits (1970s-1980s):

Food baits were popularly used to trap RPW adults in coconut in South Asia. Maharaj, 1973 found that metal traps filled with coconut petiole pieces were effective in collecting *R. palmarum*. Subsequently, Abraham and Kurian, 1975 found that split coconut logs smeared with fresh toddy were effective in trapping RPW in India. Later, Kurian *et. al.*, 1984 field tested 16 food attractant combinations against RPW and found that coconut logs treated with coconut toddy + yeast + acetic acid attracted the highest number of RPW adults. The drawback of food baited traps is that these have to be replenished frequently.

Discovery of the RPW pheromone (1993):

In a landmark finding Hallett *et al.*, 1993 reported the male produced aggregation sex pheromone (ferrugineol) for RPW. Pheromone trap captured RPW adults are known to be young, gravid and fertile (Abraham *et al.*, 2001; Faleiro *et al.*, 2003) and along with other RPW-IPM techniques can curtail the build-up of the pest in the field. However, controlled olfactometer studies have shown that less than 40% of the resident RPW population is attracted to the pheromone (El-Shafie and Faleiro, 2017). It is for this reason that pheromone trapping has to be combined with other IPM techniques to effectively control the pest.

After the discovery of the RPW pheromone in 1993 there have been several reports on the trapping protocols using RPW pheromone traps ranging from trap design, food baits in RPW pheromone traps, lure longevity, co-attractants, trap density etc. (Hallett *et al.*, 1999, Faleiro, 2006, Vacas *et al.*, 2016, Oehschlager, 2016). Adopting the best trapping protocols is vital for the success of the RPW trapping program (Faleiro and Al-Shawaf, 2018). Sub-standard trapping protocols can be counterproductive and pose a danger to the palms in the vicinity of RPW food baited pheromone traps that are not deployed in the field with the best practices.

- ***Trap design***

The four-window bucket trap with rough exterior is commonly used in RPW pheromone trapping programs (Faleiro, 2006). The cone shaped Picusan trap™ attracts and retains more weevils as compared to the bucket traps (Soroker *et al.*, 2015), but in large scale area wide programs the bucket trap is easier to service (change food bait and water). Further, insecticide-free funnel traps have also been reported to be effective in retaining captured weevils (Hallett *et al.*, 1999). Among the trap colors tested, black colored traps have been reported to capture higher number of weevils (Al-Saoud, 2013).

- ***RPW pheromone lure***

A wide range of RPW pheromone (4-methyl-5-nonanol) lures are available in the market. A good lure would capture more weevils and retain trapping efficiency for long in the field (Faleiro et al., 1999). Several RPW lures are known to last for three months in the field. A related ketone (4-methyl-5-nonanone) increased weevil captures by 65% (Abozuhairah *et al.*, 1996). Setting RPW pheromone traps under shade is essential to sustain lure longevity (Faleiro *et al.*, 1999).

- ***Food baits***

Food baits are known to enhance weevil captures in RPW pheromone traps (Hallett *et al.*, 1999; Faleiro, 2006; Oehlschlager, 2016). Fortnightly renewal of food baits and water in traps is essential to sustain the trapping efficiency. Fermenting dates, sugarcane, molasses, fresh coconut petiole bits are some of the commonly used food baits in RPW pheromone traps. It would be advisable to use food bait that is not only efficient, but also readily available and isn't costly. In some countries the food bait is deployed in a RPW pheromone trap in a separate container. This practice not only adds to the cost, but could also restrict the bait-lure synergy which is better when the bait is directly added to the water in the trap. Retaining captured weevils in the trap is essential. In this context, odorless insecticide / detergent is added to the food bait and water to kill the trapped weevils and prevent escapes (Oehlschlager, 1994; Rochat, 2006).

- ***Co-attractants***

Ethyl acetate is a known co-attarctant (kairomone) which when incorporated in food baited RPW pheromone traps generally increases captures by a factor of two to five (Oehlasclager, 2016). Currently the most attractive traps are those containing fermenting food and emitting both pheromone and ethyl acetate. However, incorporating ethyl acetate in large scale area wide trapping programs could substantially increase the cost. Vacas *et al.*, 2014 reported enhanced weevil captures with the 1:3 ethyl acetate/ethanol blend compared to aggregation pheromone alone. Non-standardised natural kairomones based on fermenting food baits in RPW trapping systems could be potentially replaced with co-attractants such as ethyl acetate and ethanol (Vacas *et al.*, 2016).

- ***Trap density***

How many traps should be set per unit area? In a surveillance program, 1trap/km is deployed along motor able roads so as to cover the entire area. In mass trapping programs however, RPW pheromone traps are set initially at 1trap/ha and increased depending on the intensity of the adult population in the field. However, increasing the trap density is often not sustainable as these traps have to be serviced. This could be overcome by going in for bait free/trap free trapping by using dry traps (Electrap™: Saroj *et al.*, 2017) and attract and kill technique (Faleiro *et al.*, 2018).

- ***Service-less trapping* (*Dry trap/Attract and Kill*)**

Stand-alone RPW pheromone traps without the food bait and water have been advocated in the past (El-Shafie and Faleiro, 2017). The Electrap™ is a dry trap and offers service-less trapping option for RPW especially in areas where the trap density has to be increased due to high weevil activity (Al-Saroj *et al.*, 2017). Recently Gonzalez *et al.*, 2018 examined the Electrap™ with and without mirrors in the chamber and compared the effectiveness of the Electrap™ vs the standard and modified bucket traps using *R. palmarum* as a surrogate organism. Their findings indicate that mirrors are not necessary for attraction of *R. palmarum* to the Electrap™ and that "serviceless" bucket traps are equally attractive. Attract and Kill (A&K) also known as lieu and kill is another service-less trapping option. Here the insect pest attracted by a semiochemical (pheromone) lure, is not "entrapped" at the source of the attractant as in mass trapping, but instead the insect is subjected to a killing agent, which eliminates affected individuals from the population after a short period (El-Sayed *et al.*, 2009). El-Shafie *et al.*, 2011, first reported the use of commercial A&K formulation for RPW (Hook-RPW™: 15% ferrugineol and 5% cypermethrin). Subsequently, Faleiro *et al.*, 2018 reported extensive field trials from Saudi Arabia and India with A&K systems against RPW (Hook-RPW™; Smart Ferrolure™). A&K for RPW control is a frontier technology that deals with the adult population in the field for at least four months once deployed, unlike the traditional preventive insecticidal sprays and is specially suited for neglected plantations with high weevil activity and are difficult to access. RPW-A&K is a flow able waxy paste deployed directly on the palm as a 3-4g dollop. The dollop hardens in a few minutes after application. It is recommended to use 1 A&K dollop/palm, where weevil activity is medium-high (3-5 weevils/trap/week) and 2 dollops / palm, where weevil activity is high to very-high (> 5 weevils/trap/week).

- ***Smart traps***

Recording of weevil captures is essential in decision making and validation of RPW control programs. Furthermore, food baited RPW pheromone traps have to be periodically serviced (renewal of food bait and water) which is not sustainable in area-wide trapping programs. In this context it is essential to have smart trapping devices for the efficient management of RPW that automatically record weevil capture data (Potamitis *et al.*, 2009; Aldhryhim and Al-Ayedh, 2015) and also eliminate trap servicing. Recently the Picusan trap™ has been modified and made smart for automatic recording of weevil captures and available in the market as Rhynchos™. GIS aided *SusaHamra* App developed by FAO for RPW-IPM data collection and interpretation are recent advancements aiding in RPW trapping programs.

- ***Attract and infect***

There are several reports on the use of entomopathogenic fungi (EPF) as biological control agents against RPW (Mazza *et al*., 2014). Noteworthy being the use of *Beauveria bassiana* solid formulation with high RPW mortality and persistence applied both as a preventive and curative treatments for RPW control (Guerri-Agullo *et al*., 2011). Soroker *et al*., 2015 proposed using attract and infect technique to strengthen biological control efforts against RPW using EPF. The possibility of infecting RPW adults with *B. bassiana* using pheromone traps was demonstrated through laboratory and semi-field cage studies (Hajjar, 2015).

- ***RPW Repellents***

Guarino et al., 2013 reported α-pinene, when used singly or in combination with methyl salicylate or menthone to be a potential repellent against RPW. Reports from India suggest that coconut plantations with intercrops (fruits and spices) recorded less incidence of RPW as compared to mono-cropped gardens due to the releases of stimulo-deterrent volatiles in plantations with intercrops that probably orient weevils away from such gardens (Josephrajkumar *et al*., 2019). There is a possibility of identifying and deploying insect repellents to protect palm injuries and in push-pull strategies. This technique need further testing.

Conclusion

RPW semiochemical mediated technology has come a long way since 1917 when fermenting kitual palm (*Caryota urens)* stem was found effective in trapping adults of RPW. The landmark discovery of the RPW pheromone in 1993 work on trapping protocols using food baited pheromone traps has seen the wide use of pheromone trapping technology in RPW-IPM programs. Future technologies on RPW semiochemical mediated techniques need to focus on the development of smart traps to eliminate manual data recording and trap servicing, that advance service-less technologies involving dry traps and also a combination techniques related to attract and kill (pheromone-insecticide), attract and infect (pheromone-EPF) and push-pull (repellent-pheromone) strategies.

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Questions/Answers – International Webinar ***Advances in Red Palm Weevil Research and Management, 08 September, 2020*** ***Don Bosco College of Agriculture-Goa, India*** ***(International Year of Plant Health Event)***		
Sr. no.	**Question**	**Answer**
1.	How to differentiate morphologically between *R. ferrugeneus and* R. *vulneratus*?	Wattanapongsiri, A. 1966. A revision of the genera *Rhynchophorus* and *Dynamis* (Coleoptera: Curculionidae). Bangkok, Thailand, Department of Agriculture Science Bulletin 1, 328 pp, gives a clear account of the morphological differences between various *Rhynchophorus* species. Following are the main points of differentiation between R. *ferrugeneus and* R. *vulneratus*? **1. Colour variation (Pronotum/Elytra):** Pronotum colour variation distinctly different in R.vulneratus and *R.ferrugineus.* *R.vulneratus* has distinct black elytra , *R.ferrugineus* has distinct orange elytra (rare to see heavy black pigmentation of elytra in *R. ferrugineus*) **2. Infestation pattern (Behaviour):** Slow and restricted in case of *R. vulneratus* and rapid and wide spread in case of *R. ferrugineus* **3. Geographical Range:** Limited to S. East Asia / California in case of *R. vulneratus*. Almost worldwide in case of *R. ferrugineus*
2	What are essential measures to take to avoid the dispersion of pest between different Zones?	It is important to implement quarantine regulations to avoid the dispersion of RPW indifferent areas/zones within a country. For details please see FAO publication on "**Red**

		Palm Weevil: Guidelines on the management practices" is now available online on the following link: http://www.fao.org/3/ca7703en/ca7703en.pdf
3	How to control RPW apical infestation of date palm?	The same measures applied to control RPW in Canary Island date palm. Such infestation is rare in date palm. It can occur in male date palms. It can be prevented by soaking with insecticides the bases of the leaves but has to be repeated very often. Palms can also be injected but in fruit bearing palms enough time should be allowed before harvest so that residues do not accumulate in the fruit (Ferry and Gomez 2014). For curing palms infested at the crown level, mechanical sanitation can also be applied using the same protocol that we have developed for *P. Canariensis* (Ferry and Gomez, 2008). Injection can also be applied using the same protocol as for prevention (but not with biological products as no method for their endophytic colonization has yet been developed) but, if the palm is more than 2-3 meters high, the insecticide must be injected close to the crown (but below at least 1 meter from the apical bud). The dose used for preventive treatment (injection at the trunk base) is efficient on larvae at the first instar stages but not at older stages present in infested palms of more than 2-3 meters height.
4	Is RPW attack of palms closely linked to other pests as rhinoceros beetle or to the existence of wounds as entry doors to the plant?	There is weak evidence that rhinoceros beetle facilitates infestation by RPW in date palm (Al-Ayedh & Al Dhafer). In coconut the relationship is stronger. However, injuries on the palm especially during frond and offshoot removal results in the release of palm volatiles that attracts the weevil for oviposition resulting in infestation.
5	Whether mentioned chemicals are having label claim for coconut?	Label expansion for imidaclorpid in coconut is currently in progress in India.
6	Pheromene trap, it has 2 side effects one to indicate RPW,	Pheromone traps if used by adopting the best protocols specially with regard to trap servicing

	the second one is to attract RPW to healthy trees, the question is where we can use it especially in border farms.	(fortnightly renewal of food bait & water), will eliminate the risk of the attracted weevil going to the palm instead of the trap. In small farms it is advisable to place the traps on the border. However, in large farms traps could be placed along the roads within the farm. Palms close to the trap can be also treated with preventive treatments. Each purpose has its own protocol. Detection has different protocol than mass trapping or control trapping.
7	Early detection of RPW is difficult for farmers to identify, what about entomologists?? is it difficult to identify the infection in early stage	Early detection of infested palms is equally difficult for farmers and entomologists alike as the pest is hidden. But early symptoms of infestation are well typified and farmers and their workers, if involved in the RPW control and well trained can perfectly find these symptoms.
8	Is anybody is working on IPM of palm moth (*Paysandisia archon*) Please let me know. Shiroma. sathyapala@fao.org	Some scientists in France and Spain are still working on this pest and have published scientific papers. EPPO data sheet on the pest offers valuable information on this pest. EPPO (2020) *Paysandisia archon*. EPPO datasheets on pests recommended for regulation. Available online. https://gd.eppo.int Forest Research Institute – Hellenic Agricultural Organization Demeter, Greece is another potential source.
9	Did the entomogenic fungus *Metarhizium anisopliae* tested against the RPW as biological mean to control it	Yes, there are reports (Ghazavi and Avand-Faghih (2002), Merghem (2011), Francardiet al. (2012) that *Metarhizium anisopliae* is a biological control agent of RPW especially the adults. However, these findings are mostly restricted_to the lab. Ghazavi, M., Avand-Faghih, A., 2002. Isolation of two entomopathogenic fungi on red palm

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Answers to the questions have been provided by the Guest Speakers at the Webinar