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REVIEW ARTICLE

Semiochemical based pest management of coconut red palm weevil, *Rhynchophorous ferrugineus* (Dryophthoridae: Coleoptera).

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ABSTRACT: Red palm weevil (RPW) has been a devastating pest of the palms. Originally a pest of coconut palm in India, it has spread across to various hosts. Mortality caused to host by its damage has caused RPW to gain pest of national interest in many countries. With limited success attained using the current management practices that includes mechanical and chemical control methods, semiochemicals are gaining popularity by growers mainly due to desirable outcome and being eco-friendly in the pest management. *R. ferrugineus* weevils are attracted to early fermentation volatiles feeding on which they produce aggregation pheromone attracting their conspecifics. Use of pheromone in isolation has limited success in field, use of food baits in tandem with pheromone strongly enhances the attraction of the weevil. Use of food bait as such in traps needs frequent servicing and this is overcome by identifying the blends derived from food bait and using them in lieu of food baits as such will reduce the need to servicing of traps at frequent intervals. The efficacy of semiochemicals is enhanced by identifying the nanomatrix for controlled delivery that would aid in better spatio temporal release there by increasing the field life of the lure over the conventional polymer-based dispensers. Synergism to pheromone by the volatiles emanating from palm tissues and food bait coupled with improved delivery matrix will scaleup the use of pheromone by farmers there by reducing the dependence on chemical insecticides for RPW management.

Keywords: Red palm weevil, *Rhynchophorus ferrugineus,* semiochemical management

INTRODUCTION

In India, coconut, *Cocos nucifera* is cultivated in divergent climate and soil, ranging from loamy, coastal sandy, alluvial, clayey and reclaimed soils (CDB, 2018). Its grown in 2.08 million ha in India (Sairam and Jayasekhar 2018)with over 10 million people involved in cultivation, post-harvest processing and marketing related activities (Lathika and Kumar, 2005). Various biotic and abiotic factors are responsible for limiting the coconut production in the country. Being a perennial crop, coconut palm is subjected to attack by an array of pests round the year. Though there are over 750 insect species (including the ones that directly feed and those which are only associated) recorded on coconut palm (Lepesme,1947), only a few are of economic importance (Lever,1969; Hashim *et al.,* 2013). All parts of the palm *viz*., leaves, stem, root, inflorescence and the nuts are subjected to attack by pests. In Kerala the annual loss due to pest complex in coconut has been estimated to be 618.50 million nuts (Abraham, 1994). Among the major pests, coconut red palm weevil (RPW), *Rhynchophorous ferrugienus* is a serious pest of concern. It is also known as Asiatic palm weevil (Avand-Faghih ,1996), coconut weevil or Indian palm weevil (Cox, 1993). It feeds on the soft succulent tissues of palm species (Murphy and Briscoe 1999; Faleiro, 2006; Oehlschlager, 2010).

Originating in South-East Asia (Lefroy, 1906; Gosh, 1912; Brand, 1917), this polyphagous pest (Al-Ayedh , 2008; Sadder *et al.,* 2018) has spread to Middle Eastern countries, parts of Iran , Africa, few countries of the European Union and Western coast of the United States of America (Avand-Faghih, 1996; Barranco *et al.,*1996;Abe *et al.,* 2009; USDA-APHIS-PPQ, 2010; EPPO, 2014; Yan *et al.,* 2015; CABI/EPPO, 2016). RPW was recorded as a serious pest of date palm *Phoenix dactylifera* (Brand, 1917). Considering the damage, it causes to date palms it is considered as category-I pest of the date palm by FAO (Faleiro, 2006).Apart from *R. ferrugineus, R. curentatus* (Wattanapongsiri, 1966),*R. palmarum*(Jaffe *et al.,* 1993), *R. phoenicis* (Gries *et al.,* 1994), *and R. vulneratus* (Kurian*et. al.,* 1984) have also been reported to attack palms.

BIONOMICS OF RPW

The female commences oviposition from 1 to 7 days after mating. It deposits the eggs after scooping out the tissues with its rostrum (Nirula, 1956.). Creamy white, long and oval shaped eggs hatch in 2 – 3 days. The egg measures 2.62 mm in length and 1.12 mm in width. The pre oviposition period lasts for about five days and the oviposition continues for another 25 – 65 days. An individual female lays up to 276 eggs and its incubation period ranges from 2 – 3 days (Abraham *et al.,* 2002). The grubs are whitish and apodous with a swollen median; the head is armed with strong mandibles. The grub's tunnel into the inner tissues and feeds on them. The grub period ranges from 36 – 78 days. The grub forms a cocoon with the vegetal debris and the pupal stage lasts for about 12 to 33 days (Nair, 1978).

The adult weevil is ferrugineously brown with long curved and pointed snout. Males are differentiated from females by a tuft of hairs on dorsal side of the snout. The life cycle is completed in four months and the females are short lived than males (Abraham *et al.,* 2002).

HOST RANGE AND DAMAGE SYMPTOMS

RPW infests around 40 different palm species (Anonymous 2013; Al-Dosary *et al.,* 2016) but the preferred host plants of RPW are coconut (*Cocos nucifera),* Canary Island date palm (*Phoenix canariensis)* and date palm (*P. dactylifera)*(Faleiro *et al.,* 2014). Damage caused due to cultural operations in palms (Jaffe *et al.,* 1993), feeding damage by rhinoceros beetle (Molet, 2013; Chakravarthy *et al.,* 2014) and the incidence of bud rot predisposes the palms to attack by RPW (Abraham *et al.,* 1998). RPW adult females have high fecundity (more than 300 eggs) with 90 per cent hatchability (Abraham *et al.,* 2002; Faleiro *et al.,* 2003a). On emergence, the apodous larvae feed on the internal soft tissue by tunneling through the palm trunk (Faleiro, 2006) which lead to withering and death of the palm. Cryptic nature of the pest is a hurdle in identification of the weevil attack in the early stages (Vidyasagar, 2016) and to carry out curative measures (Rajamanickam *et al*., 1995; Avand -Faghih, 1996; FAO, 2017). There are overlapping generations of weevils in the palm at a given point of time (Justin *et al.,* 2008; Llacer *et al.,* 2010; Giblin- Davis *et al.,* 2013). Feeding damage by male and female RPW are lethal, but female population is a greater concern as they aid in perpetuation (Salama *et al.,*2009).

CURRENT MANAGEMENT PRACTICES

RPW is effectively managed by adopting integrated pest management (IPM) practices (Abraham *et al.,* 2000; Al-Ajlan 2008 and Al-Dosary *et al.,* 2016). The key components of IPM are surveillance (Al-Shawaf*et al.,*2013), field sanitation, prophylactic treatment for rhinoceros beetle and bud rot, cultural control and curative treatment with insecticides (Faria and Wraight, 2001). Availability of pesticides and ease of application is the reason for its adoption as a curative measure for managing RPW (Abraham *et al.,*1975; Faleiro 2006; Nair*et al.,* 2000; Dembilio*et al.,* 2015; Llacer*et al.,* 2010 and Vidyasagar, 2016). Indiscriminate use of pesticides leads to development of insecticide resistance and build up of pesticide residues in harvested commodity (tender coconut and coconut) which is consumed without processing (Wakil *et al.,*2018; Ferreira *et al.,* 2015; Brito *et al.,*2002; Faleiro, 2006; Vidyasagar, 2016). Hence, an alternative eco-friendly approach is needed to combat RPW. Biological control is an option, but the timely availability and the cryptic nature of the pest is a hurdle in its use (Van Driesche and Hoddle, 2007; Murphy and Briscoe, 1999; Faleiro 2006; Yasin *et al.,*2017). Exploiting the ethology is an eco-friendly measure to manage the RPW (Vacas *et al*., 2014*).*

OLFACTORY RESPONSE IN RPW

Adults of RPW relies on the olfactory cues to find its food, oviposition site, mate and habitat. Olfaction in RPW is mediated by a pair of antennae that is geniculate (Eman*et al.,* 2012). Antennae perceives chemical cues from the environment. Odorant binding protein transport the odorants to the olfactory receptor neurons where it generates electric signals that is transmitted to higher centers of the brain. The signals in combination with other stimulus in brain is translated into behavioral response by the motor system (Buck and Axel, 1991;Leal, 2013). During the process of olfactory processing, the odorants bound to the receptors are degraded by odorant degrading enzymes (ODE) (Paolo Pelosi, 1996; Antony *et al.,* 2016).

SEMIOCHEMICALS FOR RPW MANAGEMENT

Exploiting the chemo ecological approaches to manage RPW in India was reported by Abraham *et al.,*(1975). The coconut petioles smeared with fresh toddy placed in coconut gardens were used for attracting the RPW adults. Mixture of toddy with yeast and acetic acid when smeared on coconut log attracted higher number of *R. ferrugineus* adults (Kurian *et al.,* 1984).

R. ferrugineus weevils are opportunistic oligophages to early fermenting volatiles like ethanol emanating from woundedhost(GunatilakeandGunawardane,1986).RPW adults on feeding the palm tissue produce an aggregation pheromone (4-methyl-5-nonanol) that attract their conspecifics. Evidence of male produced aggregation pheromone was established in laboratory by Abraham (1987). This led to synthesis of aggregation pheromone 4-methyl-5-nonanol and 4-methyl-5 nonanone (9:1) by Hallet *et al.,* (1993). Ferrugineol developed by Grignard reaction with butyl magnesium bromide and 2 methyl pentanal attracted the weevil(Gunawardena and Bandarage, 1995). Area wide management of RPW in Kerala by mass trapping revealed that 74% of the trapped weevils were females (Jayanth *et al.,* 2007). Trapping of females prior to oviposition will help down to scale down newer infestations.

The RPW pheromone 4-methyl-5-nonanol and 4-methyl-5 nonanone (9:1) were loaded into dispensers ranging from polymer membrane, polypropylene vials, glass capillaries, alginate beads, thermoplastic spatula and plastic cans (Faleiro *et al.,* 2000; Faleiro and Satarkar, 2003). The release rate of pheromone loaded in polymer membrane ranged from 3 – 10 mg / day. Release of 3 mg of ferruginol / day was reported to be effective in trapping RPW(Hallet *et al.,* 1999). In contrary to this, lower release rate @ 0.48 mg/ day showed a sustained efficiency in trapping of weevils (Faleiro *et al.,* 2011). High pheromone release rates necessitate the replacement of the dispensers in the traps at regular intervals (Knight, 2013) thus making it labour intensive. Replacement of the lure in the traps were suggested when there was 5 % of lure left over (Faleiro and chellapan, 1999). Lures made of poly-vinyl membrane have un-even release rates (Cha *et al.,* 2013). An ideal dispenser should have a constant release rate without pheromone depletion or dispenser degradation and environmentally friendly (Millar *et al.,* 1997).

Ferrolure (Chemtica International) loaded in polymer membrane when placed in coconut gardens lasted for over 84 days (Krishnakumar and Maheshwari, 2003). Pheromone loaded in glass capillary tubes had a field longevity of 3 months (Mayilvaganan *et al.,* 2003). Nanomaterials are novel carrier for volatile organic compounds as they have a controlled spatiotemporal release rates of semiochemicals with improved climatic stability. Nanomatrix developed jointly by ICAR and Jawaharlal Nehru Centre for Advanced Scientific Research for release of volatile organic compounds required a lower load of RPW pheromone (60mg) and had a field longevity of 180 – 200 days (Subaharan *et al.,* 2014).

FOOD BAITS OF RPW

Host volatiles along with semiochemicals released by the coleopteran enhances the attraction of the conspecifics to the source (Borden, 1985). Volatiles emanating from damaged palms serve as a cue for aggregation and oviposition by RPW (Rochat *et al.,* 1993; Giblin-Davis *et al.,* 1996 and Faleiro, 2006).

Pheromones when used in isolation wasn't effective in trapping adult weevils (Faleiro, 2006). Addition of food baits (banana, sugarcane, coconut petiole) along with aggregation pheromone in the trap increased the trapping efficiency (Jaffe´ *et al.,* 1993; Oehlschlager1994; Rochat and Avand-Faghih, 2000; Faleiro and Satarkar, 2003b). The volatiles (Kairomones) released from host plant tissues or food baits act synergistically with aggregation pheromone increasing the trap catch (Weisslinget *et al.,*1994; Gries *et al.,* 1994; Faleiro and Chellappan, 1999). Addition of water to food baits in the pheromone trap aids in fermentation, there by releasing the volatile organic compounds to attract RPW adults (Vacas *et al.,* 2013). Moist fermenting tissue from various palm species, fruits, sugarcane, pineapple and molasses were attractive to palm weevils (Giblin-Davis *et al.,* 1994).

Among the VOCs released from fermenting food baits, esters are the earliest compounds formed as a result of sugar decomposition during the fermentation process. This is followed by release of alcohol and other minor compounds *viz.*, ketones and aromatic compounds (El-Sayed *et al.,* 2005). There is a variation in the odorants released from the fermented plant tissues and the healthy plants (Giblin-Davis *et al.,* 1994; Rochat and Avand-Faghih*,* 2000). Coconut petioles attracted maximum weevils between 2—5 days after their placement in the trap. From day six the trapping of RPW declined due to shift in the release of volatile profile due microbial action (Nagnan *et al.,* 1992; Hallet *et al.,* 1993). Incorporation of ethyl acetate with fermenting food and aggregation pheromone in trap enhanced the capture of RPW (Oehlschlager 1998;Al-Saoud 2013).

When food baits are used, periodic servicing of the traps is essential to maintain the efficacy of the trap, and this is laborious and expensive (Oehlschlager *et al.,*2005; Vacas *et al.,*2013). To overcome this, isolation and identification of the volatiles from food baits that cause physiological and behavioral response in RPW adult could aid in the development of blends that would replace the placement of natural food baits in the trap (Rochat and Avand-Faghih.,2000; Oeshlschlager 2010; Vibina and Subaharan, 2019). Finding the right window to trap the compounds released from fermenting host tissue is crucial in identifying the proportion of kairomones that attract the adult weevils (Vibina and Subaharan 2019).

PHEROMONE SYNERGISTS FOR RPW MANAGEMENT

Compounds that evoke physiological response in palm weevils' antennae are deciphered by electroantennography (EAG). A method was developed to record small voltage fluctuations between the tip and base of an insect antenna on applying a stimulus (Schneider,1957). Summated response of the neurons to VOCs, confirmed the presence of receptors to the odorant that determine the attraction or repulsion after processing at the higher centers of the brain. GC-EAD (Gas chromatography-electroantennograph detector) is an assay that simultaneously records the biological and chemical detection. It facilitates to understand the antennal response of insects to an array of odorants (Karimifar *et al.,* 2011) by summated response of neurons (Beck *et al.,* 2012).

Electrophysiological assay revealed that RPW antennae responded to palm esters *viz.*, ethyl acetate, ethyl propionate, ethyl butyrate and propyl acetate (Guarino *et al.,* 2011;Vacas *et al.,* 2014). Acetoin a volatile product of anaerobic fermentation of food baits was identified as an effective synergist with aggregation pheromone of *R. palmarum* (Said *et al.,*2005) and RPW in date palm field (Vacas *et al.,*2014). Acetoin present in head space volatiles of fermenting neera caused the neuronal response in adult RPW antennae. Fermenting neera when used in tandem with aggregation pheromone trapped higher number of weevils (53.2/ trap) suggesting its possibilities in the use of RPW management (Vibina and Subaharan, 2019).

Physiological and behavioral response of RPW to food baits *viz.,* banana, pineapple and coconut petiole were reported by Vibina and Subaharan (2019). Electrophysiological responses revealed that head space volatiles trapped from banana elicited the high EAG response of 0.7 mV followed by pineapple (0.65 mV) and coconut petiole (0.2 mV). Behaviorally, orientation of adult weevils to banana, pineapple and coconut petiole volatiles ranged from 70 to 75 per cent. In field assay, compounds derived from fermenting banana along with aggregation pheromone attracted a higher number of adult weevils followed by the volatiles trapped from pineapple and coconut petiole. Ethyl acetate is used along with aggregation pheromone to trap RPW (El-Sayed *et al.,* 2005). The antennal response in EAG to volatiles trapped from food baits *viz.*, banana and pineapple were higher as compared to ethyl acetate (alone) which is also a major palm ester released from food bait. This confirms that the olfactory response of RPW is not limited to ethyl acetate alone but are dependent on blend of compounds.

Blend of plant volatiles consisting of alcohols, aldehyde and esters synergized aggregation pheromone in *Rhynchophorus* spp. (Rochat *et al.,* 1993; Said *et al.,* 2005). The American palm weevil, *R. palmarum* adults were attracted to odors of pineapple, banana and coconut petiole when used as baits in traps (Jaffe *et al.,* 1993; Oehlschlager *et al.,* 1993). Among the array of odorants emitted by host plants only a few key compounds were used to locate the host. Identification of natural volatiles emitted by host plants aided in development of synthetic blends (Rhyncophorol + host volatiles) to trap *R. palmarum* (Rochat and Avand-Faghih*.,* 2000). Synergism between ferrugineol, host palm and food bait has been demonstrated both in coconut (Faleiro and Chellapan 1999; Gunawardena *et al.,* 1995) and date palm fields (Loqma and Alqaeit 2002; Abuagla and Al-Deeb, 2012). Food volatiles (banana, pineapple, coconut petiole) trapped by headspace volatile entrapment assay loaded in a polypropylene tube when used in coconut plantation @1 to 2 trap / ha. trapped higher number of weevil (Vibina and Subaharan 2019).

A control program directed against red palm weevil adults by exploiting the odorants from the volatile released from food baits when used in tandem with aggregation pheromone of RPW has the potential to limit the population buildup in addition to reducing the number of palms attacked. Considering the success, addition of food bait or blends with aggregation pheromone placed at 1 trap /ha.was recommend to the farmers to increase the efficacy of mass trapping in India (Rajan and Nair 1997; Faleiro 2006; Murugan, 2012; Subaharan et al., 2014; Vibina and Subaharan, 2019).

CONCLUSION

Among the RPW management measures suggested the semiochemical based mass trapping of RPW can be adopted with ease. It also fits well into the IPM packages devised for managing RPW. Technology is best adopted when it is less laborious and economical. Identifying the volatiles from food baits of RPW and using them in tandem with aggregation pheromone will do away with the need to frequent servicing of traps during the times were food baits were used as such. Devicing a controlled releasing matrix for delivery of semiochemical will scaled down the load of chemistry and increase the period of field efficacy in trapping weevils which ultimately scale down the cost of using the technology. Semiochemical based approach is well suited for monitoring, mass trapping and area wide management of RPW.

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