Studies on service free semiochemical mediated technologies to control red palm weevil *Rhynchophorus ferrugineus* Olivier based on trials in Saudi Arabia and India

J.R. Faleiro[1], Abdul Moneim Al-Shawaf[2], H.A.F. El-Shafie[3] and Samir Pai Raikar[4]

(1) Food and Agriculture Organization of the UN, Goa, India, email: jrfaleiro@yahoo.co.in; (2) Centre of Date Palm and Dates, P.O. Box 43, Al-Hassa-31982, Saudi Arabia; (3) Date Palm Research Center of Excellence, King Faisal University, P.O. Box 400, Al Ahsaa-31982, Kingdom of Saudi Arabia; (4) Godrej Agrovet Limited, Valpoi, Goa, India

Abstract

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The red palm weevil (RPW) *Rhynchophorus ferrugineus* Olivier (Coleoptera: Curculionidae) is key invasive pest causing wide spread damage to date palm *Phoenix dactylifera* L. in the middle east and north Africa where it is designated as a category-1 pest by the Food and Agriculture Organization of the UN. Food baited pheromone (ferrugineol) traps have been widely used to both monitor and mass trap adult RPW in palm based agro-ecosystems all over the world since early 1990s. However, due to inherent problems associated with the periodic replacement of the food bait and water (trap servicing) in the traditional pheromone trap, pheromone trapping in area wide IPM programmes to control the pest have become costly and unsustainable. This article presents an overview of the field studies were carried out in Saudi Arabia and India to evaluate service-less trapping techniques of RPW using i) trap free "Attract and Kill" technology and ii) dry trap designed on the principle of electromagnetic communication and olfaction in insects. While "Attract and Kill" studies were carried out in three locations in the Kingdom of Saudi Arabia and one location in India, the dry trap was tested only in Saudi Arabia. Multiple field studies to evaluate "Attract and Kill" tools against RPW showed that large numbers of the adult weevils could be eliminated without the additional effort involved in the periodic servicing associated with the traditional food baited pheromone traps. Furthermore, comparative efficiency of the service-less dry pheromone trap against the traditional food baited traps, revealed that weevil captures in both the dry trap and the food baited traps were statistically similar. The above semiochemical mediated techniques offer sustainable trapping solutions for RPW management, and could be deployed especially in areas where the trap density has to be increased due to high weevil activity.

Keywords: *Rhynchophorus ferrugineus*, semiochemicals, attract and kill, dry trap, repellents.

Introduction

The red palm weevil (RPW), *Rhynchophorus ferrugineus* Olivier (Coleoptera: Curculionidae), is an internal tissue borer attacking palm trees in diverse agro-ecosystems worldwide (Abraham *et al.*, 1998; Milosavljević *et al.*, 2019). During the last three decades, its host range has extended to 40 palm species from only four palm species it was reported to attack during the 1960s. This ten-fold leap in the host range and also increasing geographical expanse of RPW has been mainly after it gained foot hold on date palm *Phoenix dactylifera* L. in the Middle-East during the mid-1980s, where it entered and spread through infested planting material (Al-Dosary *et al.*, 2016; Giblin-Davis *et al.*, 2013). Palms transported within national and across international boundaries for farming and ornamental gardening is the main cause for the spread of this hidden pest which moves through infested planting material (Faleiro, 2006; Milosavljević *et al.*, 2019). Inadequate phytosanitary measures and weak enforcement of quarantine regulations at the national, regional and international levels, coupled with constraints in early detection of infested palms due to lack of efficient and easy to use RPW detection devices, along with the inability of known biological control agents like entomopathogenic nematodes and fungi (EPNs/EPFs) to attain and sustain desired control levels of the pest in the field makes RPW control extremely difficult and challenging (Dembilio and Jacas, 2012; Faleiro, 2006; FAO, 2017).

At the farm level, RPW control mainly revolves around pheromone (ferrugineol) trapping, visual detection of infested palms, preventive and curative chemical treatments, and eradication (removal) of severely infested palms. Food-baited RPW pheromone traps are used both for monitoring and also mass trapping the pest (Faleiro, 2006). However, regular renewal of the food bait and water in the traditional RPW pheromone that are commonly used trap makes trapping costly and unsustainable in the long run.

Background

The oldest form of communication among living organisms in the biosphere is through chemical cues. These cues, generally termed as behaviour modifying compounds (BMS) or semiochemicals, have been used for insect pest management. Insect sex pheromones are widely used for the management Lepidopteran insect pests, while aggregation pheromones are commonly used to manage Coleopteran pests (Wyatt, 2003). Due to their natural origin, low persistency in the environment, and species specificity semiochemicals are considered safe and environmentally friendly molecules that are harmless on non-target organisms (Horowitz *et al*., 2009). Despite general progress in chemical

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ecology and potential of semiochemicals, their commercial exploitation in date plantations has been slow. Effective attractants are known for only a few date pests and even for those, their use is usually limited to monitoring (Soroker *et al.*, 2015).

Prior to the synthesis of the RPW aggregation pheromone (ferrugineol) in 1993, trapping of adult weevils in coconut was carried out using food baits, fermenting palm wood, split coconut logs smeared with fresh toddy (Abraham and Kurian, 1975). With the characterization and synthesis of the male produced aggregation pheromone by Hallett *et al*., 1993, food baited bucket pheromone traps have been widely used in both, RPW monitoring and mass trapping programs, where weevil captures are female dominant (Faleiro, 2006). Insect-produced chemicals generate synergy for attraction with host plants, especially in the order Coleoptera (Borden, 1985) and therefore, the RPW pheromone (ferrugineol: 4-methyl-5-nonanol) when used in association with a food bait (dates, sugarcane, banana etc.) acts in synergy to enhance weevil captures, as compared to when the pheromone and food bait are used separately (Hallett *et al*., 1999; Oehlschlager, 2016). In this respect, the chemical co-attractant (ethyl acetate) when used in RPW pheromone traps is known to increase weevil captures (Oehlschlager, 2016). Ferrugineol in association with 10% of its ketone derivative (ferrugineone) is also known to enhance captures (Abozuhairah *et al.*, 1996). Co-attractants based on fermenting compounds, ethyl acetate and ethanol, could improve the attractant level of ferrugineol and potentially replace non-standardised natural kairomones in RPW trapping systems (Vacas *et al.*, 2016).

Although olfactometer assays have shown that RPW pheromone trapping accounts less than 40 % of the population (El-Shafie and Faleiro, 2017), trap captured female weevils are known to be young, gravid and fertile which helps to curtail the build-up of the pest in the field (Faleiro *et al*., 2003). However, foods baited pheromone traps have to be regularly serviced, when the food bait and water has to be renewed, which is costly and not sustainable in the long run especially in an area-wide operation involving several hundred traps. Besides trap servicing, recording of weevil captures is essential in decision making and validation of RPW control programs. In this context, it is essential to have smart trapping devices for the efficient management of RPW (Aldhryhim and Al-Ayedh, 2015). RPW semiochemical mediated technologies of the future therefore need to focus on the development of technologies that not only eliminate the need of trap servicing and develop lures that stand-alone but also which could be deployed in a smart trapping device for the overall improvement in the trapping efficiency, data collection and transmission (El-Shafie and Faleiro, 2017).

This paper looks at three service-free RPW semiochemical mediated technologies *viz.* i) attract and kill, ii) dry pheromone traps, and iii) RPW repellents tested in Saudi Arabia and India.

Overview of service-free RPW semiochemical mediated technologies

Attract and Kill - In Attract and Kill (A&K), 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). A&K technique is used to control insect pests in a wide range of crops. Brown marmorated stink bug *Halyomorpha halys*, an invasive, polyphagous insect that causes serious economic injury in particular to specialty crops like apple in the United States is an important example where this technique is used**.** Several case studies in which A&K has been used with the aim of long-term pest management include pink bollworm, Egyptian cotton leaf worm, codling moth, apple maggot, biting flies, bark beetles, and the eradication of invasive tephritid fruit flies and boll weevils (Camelo *et al.,* 2007; El-Sayed *et al.,* 2009; Hossain *et al.,* 2005; Marfa-Neto *et al.,* 2014; Mazomenos *et al.,* 2002; Morrison *et al.,* 2015). The technique is used in integration with other IPM methods.

In the case of RPW, the potential of using A&K as a component of the RPW-IPM strategy was first studied with a commercial formulation (Hook-RPW™: 15% ferrugineol and 5% cypermethrin) by El-Shafie *et al.* (2011). Subsequently, extensive field trials were carried out in Saudi Arabia and India with A&K systems (Hook-RPW™; Smart Ferrolure™).

A&K formulation against RPW developed by ISCA Technologies, USA (Hook-RPW™) was extensively field tested in date palm in Saudi Arabia; while A&K systems against RPW by Chem Tica International, Costa Rica (Smart Ferrolure™) were tested for palm protection against RPW in large field trials in date and oil palm plantations in Saudi Arabia and India, respectively (Faleiro *et al.,* 2016a; Faleiro *et al.,* 2016b).

Dry traps - Stand-alone RPW pheromone traps without the food bait and water have been advocated in the past (El-Shafie and Faleiro, 2017). This will substantially cut the cost of sustaining and replenishing the food bait and water associated with the traditional RPW food baited pheromone traps commonly used in RPW-IPM programs. The Electrap™ is an advancement in this direction and offers a sustainable service-less trapping option for RPW especially in areas where the trap density has to be increased due to high weevil activity. The Electrap™ functions on the principle that insects communicate by radiations emitted from oscillating molecules (Al-Saroj *et al.*, 2017).

RPW repellents - The possibility of identifying and deploying insect repellents with pheromones in an area-wide programme involving a push-pull strategy could open a new semiochemical mediated strategy for the sustainable management of RPW. α-pinene, singly or in combination with methyl salicylate or menthone has been identified as a potential RPW repellent (Guarino *et al.,* 2013). Further studies are necessary to identify RPW repellents and quantify the extent of palm protection RPW repellents could provide.

Figure 1. RPW attract and kill systems; Smart Ferrolure paste (left) with a dead weevil and Card device (middle), Hook RPW Dollop (right)

Field trials on service-free RPW semiochemical mediated technologies in Saudi Arabia and India

Attract and Kill - In a field trial in Al-Qassim, Saudi Arabia, Hook-RPW™ (ISCA Technologies, California, USA) was applied as two-4g dollops of Hook-RPW™ (30% ferrugineol + 5% cypermethrin) to the base of the palm with a caulking gun @ 400 dollops per ha), (Faleiro, et al., 2016a). Attractiveness and killing of RPW adults were recorded throughout the experimental period of 23 weeks, in 10% of the points set in four-window bucket containers closed with a lid. The traditional food-baited RPW pheromone traps were set at 1trap/ha in A&K treated plot (10ha) and also in a control plot (8ha) without A&K.

A total of 209 weevils were attracted and killed by just 10% of the points in the A&K treated plot with Hook-RPW™. Also, the mean trap captures in RPW pheromone traps set in the experimental plot was significantly lower as compared to captures in the control plots with no A&K treatment, clearly indicating that the A&K system removed a large number of weevils in the A&K treated plot (Faleiro, et al., 2016a).

With respect to Smart Ferrolure™, two A& K systems of 'Smart Ferrolure™' from Chem Tica International, Costa Rica *viz.* i) a card A&K device and ii) paste formulation, were tested in RPW infested date plantations of Al-Ahsa, Saudi Arabia on 01 September to 23 November, 2015 and 06 September to 02 December, 2015, respectively (Faleiro et al., 2016b). The card A&K device [card: wax with 5% cypermethrin + ferrolure 700mg+ethyl acetate (weevil magnet ™)] was installed in the field (2ha) at a density of 30 points/ha (Faleiro *et al*., 2016b). The paste formulation [15% ferrugineol + 5% cypermethrin] was deployed in a 3ha plantation as a 3g dollop @ 250points/ha.

The dead weevils in the points set in containers in the trial sites revealed that both the card device and paste formulation of Smart Ferrolure™ attracted and killed RPW adults. However, the paste formulation killed significantly more weevils (16 weevils in only 10% A&K points) as evidenced from the dead weevils in the containers as compared to the card system (only 9 weevils in 50% of the points). While results with the paste were encouraging, the card exhibited significantly low killing capacity in about 45 days after exposure in the field, probably due to accumulation of dust on the card that prevented contact of attracted weevils to the insecticide.

In India, both the above card device and paste formulation of 'Smart Ferrolure™', by Chem Tica International, Costa Rica were tested in two field trials from 01 September, 2015 to 09 April, 2016 in the same RPW infested oil palm plantation belonging to Godrej Agrovet Limited, Valpoi, Goa, India. Each A&K system (paste and card) was tested in 8 ha (Faleiro et al., 2016b). In these trials, 15 % of the points were set in open containers to record weevil that get attracted and killed. In all the trial sites in Saudi Arabia and India a trap density of 1trap/ha was maintained and other routine RPW-IPM practices carried out.

From the trial in the oil palm plantation in India with Smart Ferrolure™ (Figure 2), it is evident that the paste formulation of Smart Ferrolure™ was superior as compared to the card system. RPW population reduced by 89% at the end on trial-II using the paste formulation of Smart Ferrolure™ as compared to the card system where adult population reduced by only 41% (Faleiro *et al.*, 2016b).

Dry Trap - Weevil captures in two field trials revealed that the treatments (Picusan Trap™, Electrap™ and the traditional bucket trap) were statistically similar (Al-*Saroj et al*., 2017). However, recent report (Kharrat *et al.*, 2018) based on trials carried out against *R. palmarum*, indicated

that the attraction may be due to the pheromone/synthetic attractant rather than electro-magnetic radiation, which is contrary to the claim that the functioning of the Electrap™ is based on the concept that insect communication is mediated by radiation. This mechanism of electromagnetic communication and olfaction in insects has been previously reported by several workers (Laithwaite, 1960; Callahan, 1965).

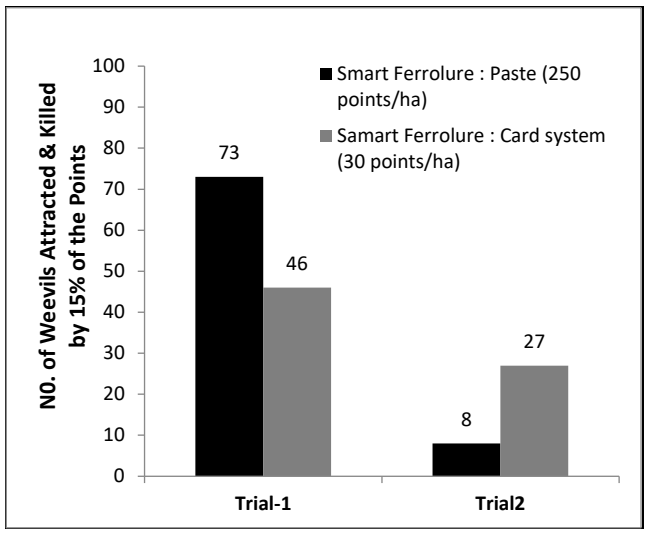

Figure 2. RPW Attracted & Killed by Smart Ferrolure™ tested on Oil Palm [01 September, 2015 to 09 April, 2016]: Goa, India. Trial-I: 01 September-30 November, 2015; Trial-2: 10 January-9 April, 2016 (Source: Faleiro *et al.,* 2016b).

RPW Repellents - A push-pull strategy deployed in combination with a repellent and attractant has been proven useful for the management of several species of bark beetles (Borden *et al.,* 2006) and needs to be tested against RPW.

Replicated field trials were carried out in Al-Ahsa between 2011 and 2012 to screen 45 know insect repellents through trap shut down studies. Four promising repellents identified (GCC patent pending) in these trials were further tested for tree protection in a 10 ha RPW infested date plantation where these repellents were installed at 50 repellents/ha, while RPW pheromone traps set at 1 trap/ha were installed at the periphery of the test plot in a push-pull design. A control plot (10 ha) without the repellent was also maintained and weevil captures in the treated and control plot were compared at the end of the experimental period (April-July 2014). In addition to the above, replicated field trials were also carried out in Al-Ahsa to ascertain the repellent potential of verbenone against RPW through trap-shut down studies (Faleiro, 2016).

Four RPW repellents were identified through trap shut-down studies with over 80% trap shut down (Faleiro, 2012). The repellents are currently being vetted for a GCC patent. Furthermore, upon testing of these repellents in a push pull system, weevil captures in plots with pheromone traps treated with the repellent recorded higher weevil captures indicating that the pest was repelled from the repellent treated plot but weevil captures in traps were statistically similar in plots without the repellent. It may be necessary to increase the repellent density per unit area from the 50 repellents/ha tested to obtain adequate repellency effect. Trials with verbenone against RPW resulted in 75% trap shut down. Further testing of these RPW repellents for palm protection is required (Faleiro, 2016). Testing RPW repellents with the service less Electrap™ or A&K technology in a push-pull system also needs to be evaluated.

Conclusion

RPW adults attracted and killed by both Hook-RPW™ and Smart Ferrolure™ in the above trials clearly indicates that a trap density of 1 trap/ha was not sufficient in trapping the adult weevils in the test plantations. Pheromone trap densities in area-wide RPW-IPM programs range from one to 10 traps per hectare (Faleiro *et al.,* 2011; Oehlschlager 2006; Soroker *et al.,* 2005;). However, increasing the trap density is often not possible due to the periodic servicing (change of food bait and water), necessary to sustain the trapping efficiency. In this context, the 'trap and bait free' A&K option could significantly augment the mass trapping programme of RPW by killing the emerging adult weevil population in the field. A&K technology can successfully eliminate adult RPW population. The technology serves as an excellent tool to manage RPW population where infestations are high, or in plantations that are inaccessible and neglected and could significantly strengthen the on-going pheromone trap based RPW-IPM strategy particularly in plantations where the pheromone trap density has to be increased to effectively mass trap the adult population. The cost involved in the periodic servicing associated with the traditional food-baited pheromone traps is effectively eliminated with this 'bait and trap free' technique of controlling the adult RPW population in the field. However, a minimum of one food baited pheromone trap/ha is required to be maintained in an area-wide RPW control programme to gauge weevil activity in the field. Furthermore, A&K has the potential to do away with the need to take up routine periodic preventive insecticide sprays. The technique has been used in RPW-IPM programs in date palm, the canary palm and coconut in Mauritania, Abkhazia in the Republic of Georgia and Malaysia, respectively.

All safety precautions (wearing of gloves, mask, foot wear, etc.) need to be complied with while applying RPW A&K formulation in the field. In case of allergic reaction or coming in direct contact with the product, further application should be stopped, immediate medical assistance sought and the manufacturer contacted.

The Electrap™ is an efficient service free semiochemical mediated technology against RPW and can be incorporated in RPW-IPM programs. However, known RPW repellents need further testing to be incorporated in an RPW-IPM program involving a push-pull strategy.

الملخص

فاليرو، جو رومينو، عبد المنعم الشواف، حمدتو عبد الفراج الشفيع وسمير باي رايكر. 2019. دراساتٌ لتقنيات تعتمد على كيميائيات الاتصال ولا تتطلب صيانة لمكافحة سوسة النخيل الحمراء *Rhynchophorus ferrugineus* Olivier استناداً لتجارب في المملكة العربية السعودية والهند. مجلة وقاية النبات العربية، 37(2): 136-142.

تعدّ سوسة النخيل الحمراء *Rhynchophorus ferrugineus* Olivier (فصيلة السوس Curculionidae، التابعة رتبة غمديات الأجنحة Coleoptera) آفةً غازيةً رئيسةً لأشجار نخيل التّمر *Phoenix dactylifera* L.، وتتسبّب لها بأضرار فادحة في منطقة الشرق الأوسط وشمال إفريقيا حيث تمّ تحديدها كآفةٍ من الفئة الأولى وفقاً لمنظمة الزراعة والأغذية (الفاو) التابعة للأمم المتحدة. استخدمت مصائد الطعوم الفيرمونية (فيروجينيول) منذ مطلع التسعينات وعلى نطاق واسع في جميع أنحاء العالم بهدف الرصد والاصطياد الغزير للحشرات الكاملة لسوسة النخيل في آنٍ معاً والتي تعتمد على الأنظمة الزراعية البيئية؛ ومع ذلك فقد تكشّفت مشاكل منوطةً بضرورة الاستبدال الدوري للطعوم الغذائية والماء (صيانة المصيدة) في المصائد الفيرمونية التقليدية، ممّا جعلها مكلفةً وغير مستدامةٍ عند استخدامها على نطاقٍ واسع ضمن برامج المكافحة المتكاملة للآفة. ومع أخذ ما ورد أعلاه بالحسبان، فقد أجريت دراساتٌ حقلية في المملكة العربية السعودية والهند لتقييم كفاءة تقنياتٍ تختزل الحاجة لصيانة المصائد لاعتمادها في مكافحة سوسة النخيل، وذلك باستخدام: 1) تقنية الجذب والقتل بدون مصائد؛ 2) تقنية المصائد الجافة، والمصممة على مبدأ الاتصال الكهرومغناطيسي والشّمي عند الحشرات. تمّ تنفيذ دراسات "الجذب والقتل" في ثلاثة مواقع ضمن المملكة العربية السعودية وموقعٍ واحد في الهند، في حين اقتصر اختبار المصائد الجافة على موقع واحد فقط في المملكة العربية السعودية. أظهرت عدّة دراساتٍ حقلية قيّمت خلالها فعالية تقنية "الجذب والقتل" إزاء حشرة سوسة النخيل أنّه بات بالإمكان استئصال أعدادٍ كبيرة من بالغات الحشرة دون الحاجة لبذل جهدٍ إضافي كالذي تستهلكه عمليات الصيانة الدورية في حالة المصائد الفيرمونية الغذائية التقليدية. وعلاوةً على ذلك، فقد تبيّن بمقارنة الكفاءة النسبية للمصائد الجافة ـــ التي تتطلب صيانةً أقلّ ـــ مع مصائد الطعوم الغذائية التقليدية بأنّ اصطياد حشرة السوس متماثل في كلتا المصيدتين من الناحية الإحصائية. تقدّم التقنيات القائمة على كيميائيات الاتصال المذكورة أعلاه حلولاً للاصطياد المستدام لحشرة سوسة النخيل الحمراء ضمن برنامج إدارة هذه الآفة، والتي يمكن نشرها خصوصاً في تلك المناطق التي تستوجب تكثيف المصائد جرّاء النشاط الزائد لحشرات السوس فيها.

كلمات مفتاحية: سوسة النخيل الحمراء، كيميائيات الاتصال، الجذب والقتل، مصيدة جافة، طاردات.

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