Diel Flight Activity Patterns of the Red Palm Weevil (Coleoptera: Curculionidae) as Monitored by Smart Traps

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Diel flight activity patterns of the red palm weevil (Coleoptera: Curculionidae) as monitored by smart traps

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Abstract

The red palm weevil, *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae), is a serious pest of palm in many subtropical and tropical regions of the world. Traps baited with aggregation pheromones are important management tools used to control this weevil. The daily flight activity patterns of the red palm weevil in Saudi Arabian date palm orchards were observed using smart traps (STs) with a catch period of 3 h (8 periods daily). Conventional bucket traps (CTs) were used for comparison. The capture efficiency of the STs was not significantly different from that of the CTs. A circular statistics analysis showed that the time of adult capture in the STs was nonrandom and indicated mainly diurnal activity; few adults were captured at night. The STs revealed differential activity between the sexes. The female activity pattern exhibited 2 strong peaks at 7 to 9 AM and 4 to 7 PM, and the 2nd peak was significantly higher than the 1st peak. The male activity pattern showed 3 peaks at 7 to 10 AM, 1 to 4 PM, and 4 to 7 PM with no significant differences among the peaks. Males initiated activity before the females. The number of adults captured by STs was positively correlated with the time of sunrise and wind velocity, negatively correlated with the time of sunset and the ambient temperature, and not significantly correlated with the relative humidity. Although these patterns were consistent during the study period, they differed from a variety of other patterns reported in European and Southern Asian environments, which suggests that *R. ferrugineus* has evolved considerable behavioral flexibility in coping with harsh environmental conditions typical of hot arid date production areas in Saudi Arabia. Knowledge of *R. ferrugineus* daily activity patterns in local field environments can help managers optimize the timing of pesticide applications and other control activities.

Key Words: *Rhynchophorus ferrugineus*; time sorting; pheromone; diel activity

Resumen

El picudo rojo de la palma, *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae), es una plaga seria de la palma en muchas regiones tropicales y subtropicales del mundo. Trampas cebadas con feromonas de agregación son importantes herramientas del manejo utilizadas para controlar este gorgojo. Se observó el patrón de actividad del vuelo diario del picudo rojo de la palma en huertos de palmeras datileras en Arabia Saudita usando trampas inteligentes (TIs) con un período de captura de 3 h (8 períodos diarios). Se utilizaron cubetas convencionales (CCs) para la comparación. La eficacia de la captura de las TIs no fue significativamente diferente de la de las CCs. Un análisis circular de las estadísticas mostró que el momento de la captura de adultos en las TIs no fue aleatoria e indicó una actividad principalmente diurna; pocos adultos fueron capturados por la noche. Las TIs reveló actividad diferencial entre los sexos. El patrón de actividad de las hembras exhibió 2 picos fuertes de las 7 a 9 am y de las 4 a 7 pm, con el segundo pico significativamente más alto que el primer pico. El patrón de actividad de los machos mostró 3 picos de las 7 a 10 am, 1 a 4 pm, y de las 4 a 7 pm, sin diferencias significativas entre los picos. Los machos iniciaron su actividad antes de las hembras. Se correlacionó positivamente el número de adultos capturados por los TIs con el momento de la salida del sol y la velocidad del viento, se correlacionó negativamente con el momento de la puesta del sol y la temperatura ambiente, y no se correlacionó significativamente con la humedad relativa. Aunque estos patrones fueron consistentes durante el período de estudio, se diferenciaron de otras variedades de patrones reportados en ambientes de Europa y Asia del Sur, lo que sugiere que *R. ferrugineus* ha desarrollado un comportamiento flexible consideragle para hacer frente a las duras condiciones ambientales típicas de las áreas de producción de palmeras datileras áridas calientes de Arabia Saudita. El conocimiento de los patrones de actividad diaria de *R. ferrugineus* en ambientes de campo locales puede ayudar a los gerentes a optimizar el calendario de aplicación de pesticidas y otras actividades de control.

Palabras Clave: *Rhynchophorus ferrugineus*; tiempo de clasificación; feromona; actividad diel

The red palm weevil, *Rhynchophorus ferrugineus* (Olivier, 1790) (Coleoptera: Curculionidae), is serious pest of palms, attacking many species in countries where the insect is either native or invasive (Faleiro 2006; Ju et al. 2011; Inghilesi et al. 2013; Manachini et al. 2013; Çıtırıkkaya et al. 2014). It has spread rapidly from its native habitat to the Middle East, Europe, North Africa, and the Caribbean Islands due to the inadvertent transport of infested trees (Murphy & Briscoe 1999; Ferry & Gomez 2002; Fiaboe et al. 2012; Inghilesi et al. 2013). Also,

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cryptic behaviors of the red palm weevil provide protection from harsh weather, enhancing the survival of the weevil in a wide range of environments (Murphy & Briscoe 1999).

A synthetic aggregation pheromone has been used extensively as a primary tool in the integrated pest management of the red palm weevil (Alpizar et al. 2002; Reddy et al. 2005; Hoddle & Hoddle 2011; Hoddle et al. 2013; Vacas et al. 2013). The addition of a kairomone (ethyl acetate) paired with a bait (fermenting dates) has a synergistic effect on the response of the weevils to pheromone traps (Rochat et al. 1991; Vacas et al. 2014). Trap efficiency depends not only on the pheromone and kairomone but also on other factors such as the trap design, color, height, and the weather conditions (Hallett et al. 1999; Abuagla & Al-Deeb 2012). Conventional plastic bucket traps (CTs) (Ajlan & Abdulsalam 2000; Faleiro 2005; Abuagla & Al-Deeb 2012; Fanini et al. 2014) are used in conjunction with pheromone traps to increase the efficacy or to add new functions to the trap.

Little is known about the daily activities of the red palm weevil in palm date orchards, and the timing of the maximum rates of capture in pheromone traps varies among studies. Fanini et al. (2014) reported no nocturnal activity by adults, and they captured most adults between 6 AM and 9 AM. However, Faleiro (2005) found that the red palm weevil was most active between 12 AM and 6 AM. Both studies used CTs. The objective of this research was to study the diel activity patterns of the red palm weevil in the field by using a novel smart trap (ST). The efficacy of the ST was compared with that of the traditional trap. Our results provide new information about red palm weevil behavior under field conditions in Saudi Arabia.

Materials and Methods

EXPERIMENTAL LOCATION

The study was conducted on a commercial farm (24°13′120″N, 47°14′260″E) in the Al Karj District, 80 km south of Riyadh, Kingdom of Saudi Arabia. The farm was approximately 1,000 ha in size and contained more than 2,500 date palm trees (*Phoenix dactylifera* L.; Arecales: Arecaceae) of various varieties and ages. Other crops also were planted on the farm.

TRAP DESCRIPTION

The STs contained fixed and rotary plastic sections (Fig. 1). The external section was 40 cm in height with nine 5 × 3 cm windows below the upper rim. A cover at the top opened to suspend the pheromone lure inside (Fig. 1A). Inside the external section, a fixed funnel extended to an internal section (Fig. 1B) containing the rotary and receiving units. The rotary unit contained an oblique tube connected to a funnel at its upper portion and to a plate at its lower portion. The rotary unit was connected to a motor powered by eight 1.2 V batteries and controlled by a timer that rotated through eight 3 h sections daily. The receiving unit held eight 250 mL jars. Each jar contained 100 mL tap water and 1 date fruit. AlAyedh et al. (2013) provide a more detailed description of the patented apparatus. The CT was a plastic 5 L pail containing 4 opposing (2.5 × 1.0 cm) windows in the upper third of the trap to allow the entry of weevils (Ajlan & Abdulsalam 2000).

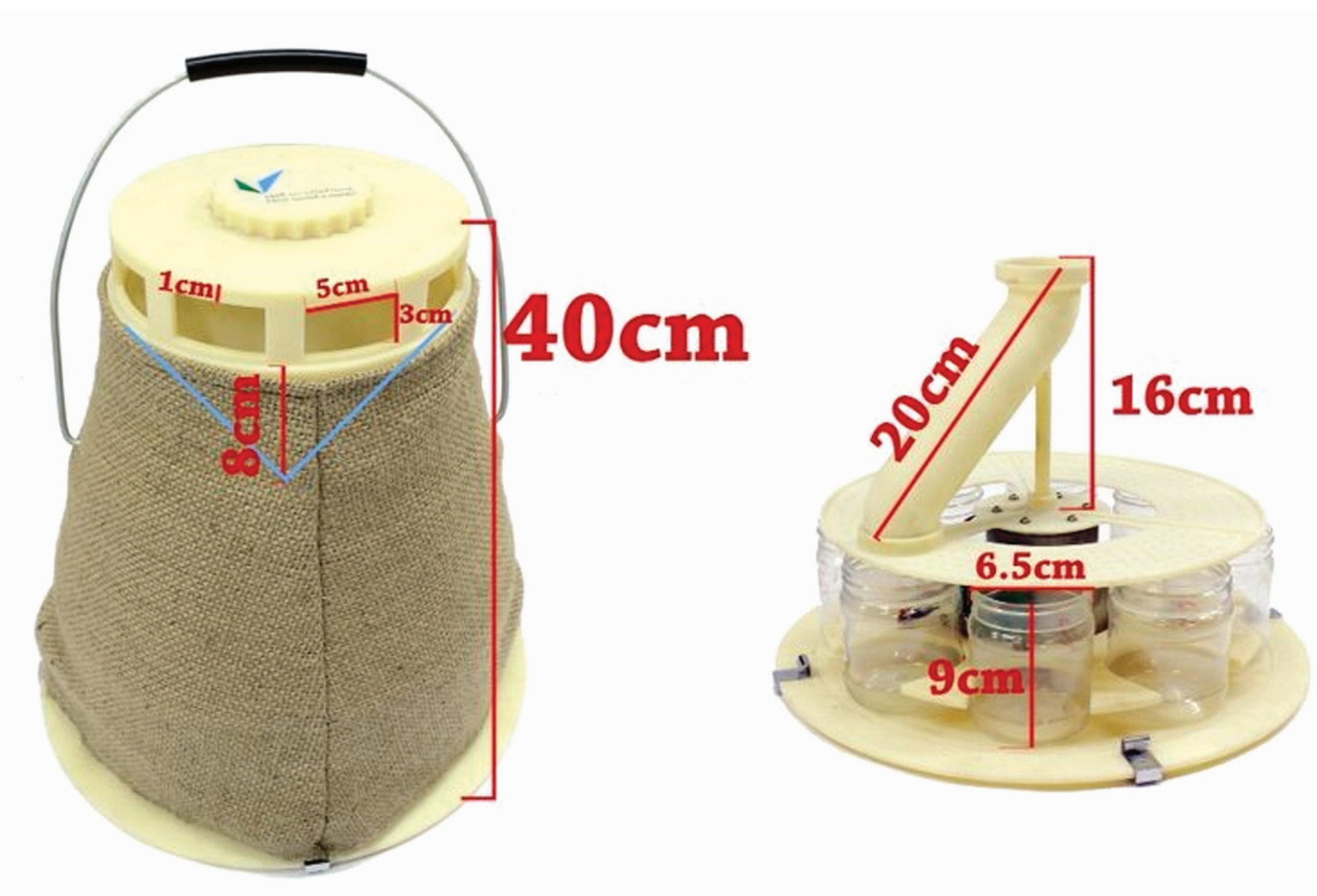

Fig. 1. External (A) and internal (B) sections of the ST.

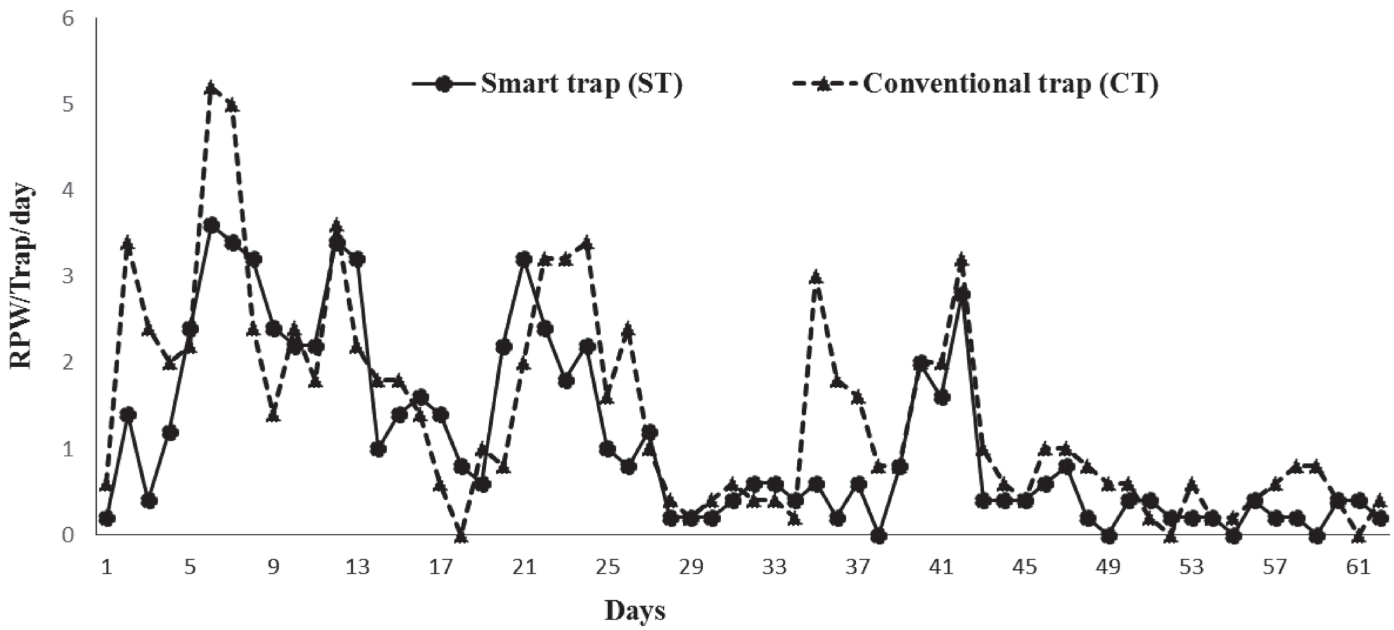

Fig. 2. Daily mean numbers of captured red palm weevils in STs and CTs.

TRAPPING PROCEDURE

The STs and CTs were wrapped with jute. The aggregation pheromone ferrugineol (9 parts 4-methyl-5-nonanol and 1 part 4-methyl-5-nonanol, purity of both components >98%; ChemTica Internacional, S.A., San Jose, Costa Rica) had a release rate of 3 to 10 mg/day. The traps were placed on the ground and distributed randomly in 2 parallel rows. The distance between the rows and the distance between traps within the same row was 80 m. Five traps of each type were placed. A HOBO® H8 data logger (Onset Computer Corporation, Madison, Wisconsin, USA) was placed on the trunk of a palm tree near each of the STs to collect microclimatic data.

The traps were inspected daily at 10 AM, and captured adults were removed and kept in small plastic containers. For the weevils captured in STs, the location of the ST in which each weevil was captured was recorded. The water and date fruits in the traps were replaced weekly. The study was carried out for 62 d, from 4 Apr to 4 Jun 2014.

STATISTICAL ANALYSES

All data were analyzed using SAS version 9.2 (SAS 2009) and Oriana version 4.02 (Kovach 2011) for the linear and circular statistics, respectively. The normality of the linear data was tested using PROC UNIVARIATE with the Shapiro–Wilk method prior to analysis of variance (ANOVA). Because the data were not normally distributed, a nonparametric Kruskal–Wallis 1-way ANOVA was performed to test the diel pattern of the captured weevils using PROC NPAR1WAY, followed by a least significant difference test for the mean ranks data comparison (Madden et al. 1982). A repeated measures analysis with the Greenhouse–Geisser correction was conducted using PROC GLM to compare the mean number of weevils captured per day by the STs and CTs (Greenhouse & Geisser 1959). Regression and correlation analyses were performed to investigate the potential relationship between the total number of weevils captured per trap per day and the patterns of sunrise, sunset, wind speed, relative humidity, and temperature. Rayleigh's Uniformity test was applied using Oriana version 4.02 (Kovach 2011) to evaluate the null hypothesis that the ST capture circular data were distributed in a uniform pattern.

Results

COMPARISON BETWEEN STS AND CTS

The CTs and STs were similarly effective in capturing red palm weevil adults (Fig. 2). Repeated measures analysis showed that the mean number of captured weevils per trap per day was not significantly different between the CTs and STs. The mean number of weevils caught per day by the STs and CTs was 1.1 and 1.4, respectively (Table 1). There was no significant interaction between day (time) and treatment (trap types) in the repeated measures analysis. Furthermore, the daily capture rates of the STs were not significantly different from those of the CTs in the same locations, although the capture rate of the ST in location 4 was significantly less than that of the CT in the same location (Table 1). The daily capture rates of both trap types were negatively correlated with the number of days since the beginning of the capture period ($P < 0.0001$ for each type; Fig. 2).

Table 1. Mean numbers (± SE) of weevils captured per trap per day ($N = 310$).

	Trap location					
Trap type	1	2	3	4	5	Type mean
Smart (ST)	0.8 ± 0.1a	1.2 ± 0.2a	1.8 ± 0.3a	0.6 ± 0.1b	1.1 ± 0.1a	1.1 ± 0.2
Conventional (CT)	1.1 ± 0.2a	1.5 ± 0.2a	2.0 ± 0.3a	1.3 ± 0.2a*	1.1 ± 0.2a	1.4 ± 0.2

Means followed by the same letter in the same row are not significantly different from each other ($P > 0.05$, least significant difference test).
*Indicates a significant difference from the other value within the column.

DIEL PATTERN OF ST CAPTURES

The circular data analysis of the ST captures revealed differences in the mean times of the captures of adult males and females across the 3 h capture periods (Fig. 3A male, 3B female, and 3C both). The mean times of capture were 11:15 AM, 12:19 PM, and 12:03 PM, respectively (Table 2). The Kruskal–Wallis test showed significant differences (F = 20.11; df = 7, 1; P < 0.0001) between the number of males and females captured in the STs during the 8 diel periods. On average, males were trapped earlier in the day than females. The least significant difference analysis revealed a binomial capture pattern for females from 7 AM to 10 AM and from 4 PM to 7 PM (F = 20.9; df = 7, 1; P < 0.0001; Fig. 4), indicating that female activity was restricted to the early morning and late afternoon periods. Males exhibited a different pattern, suggesting activity during numerous time periods (Fig. 4).

The sex ratio of the captured adults was uneven, with the number of trapped females consistently higher than that of trapped males. The mean sex ratio was 3.7:1 (female to male). The sex ratio of the weevils captured in the STs was highly influenced by the time (Fig. 4). The highest sex ratio was 5.8:1 (female to male) recorded from 4 PM to 7 PM, and the lowest sex ratio was 1.7:1 (female to male) recorded from 1 PM to 4 PM.

RELATIONSHIP BETWEEN THE NUMBER OF CAPTURES AND ENVIRONMENTAL VARIABLES

The numbers of red palm weevils captured per trap per day over the 62 d period were correlated with sunrise, sunset, wind speed, relative humidity, and temperature. There was a significant positive correlation between the time of sunrise and the number of weevils captured (Pearson correlation = 0.59; P < 0.05), indicating that more weevils were captured when sunrise occurred later in the day. By contrast, there was a significant negative correlation between the time of sunset and the number of weevils captured (Pearson correlation = −0.63; P < 0.005), indicating that fewer weevils were captured when sunset occurred later in the day. The regression intercepts and slopes were 30.97 and −4.70, respectively, for sunset, and 15.37 and 3.11, respectively, for sunrise. The capture rate was negatively correlated with temperature (Pearson correlation = −0.37; P = 0.03), positively correlated with wind speed (Pearson correlation = 0.30; P = 0.01), and not significantly correlated with relative humidity (Pearson correlation = −0.12; P = 0.38).

Discussion

A wide variety of automated traps have been designed to study the daily activity of both flying and ground-dwelling or plant-dwelling insects (Murchie et al. 2001; Stevenson et al. 2006; Guarnieri et al. 2011; López et al. 2012; Potamitis et al. 2014). The ST is the first automated trap to be field tested against the red palm weevil. The ST design allowed the daily activities of adult red palm weevils to be recorded under field conditions, providing information that will be useful for pest managers and decision makers.

The ST is durable under field conditions and can be operated continuously for months at a time on 1.2 V rechargeable batteries; the batteries were neither replaced nor recharged during the 2 mo study period. The rotary apparatus is light and does not require a strong motor, allowing the trap to be lightweight, virtually maintenance free, and capable of sustained activity. Moreover, the ST is durable under harsh weather conditions where the ambient temperature exceeds 40 °C.

The diel pattern analysis indicated that red palm weevil activity was nonrandom, with most adults trapped during the day. Fanini et

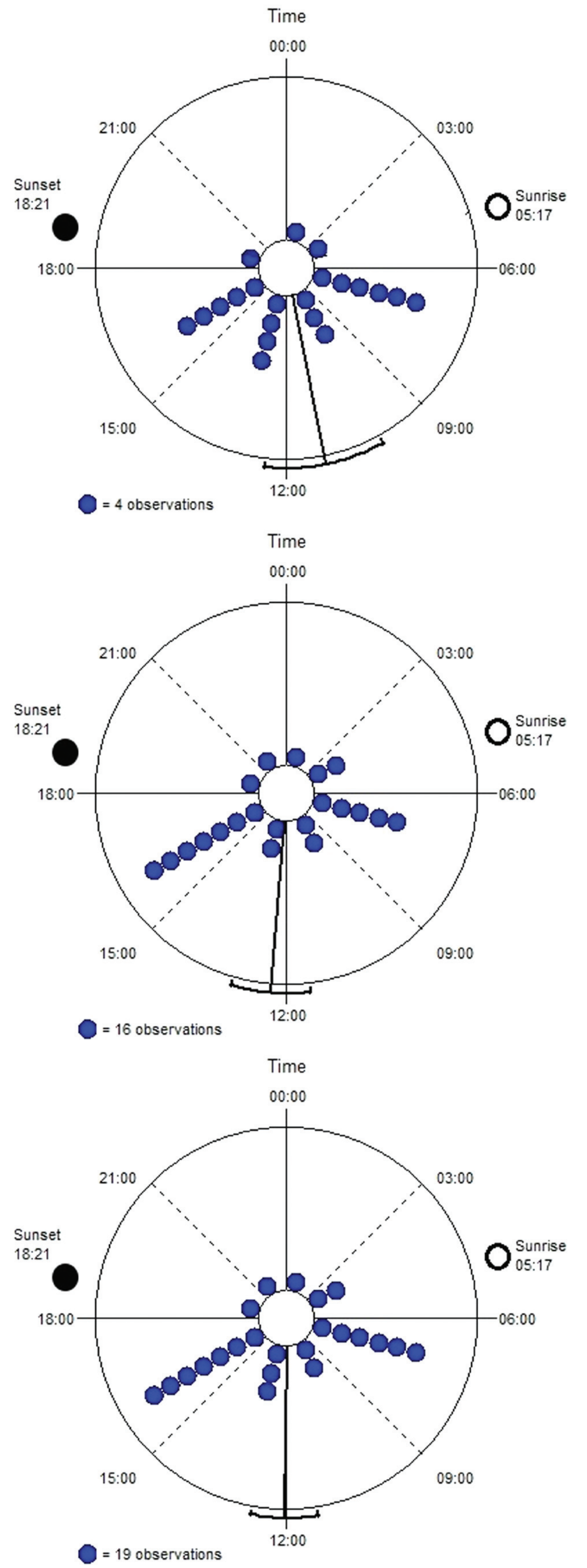

Fig. 3. Mean temporal distributions of adult male (A), female (B), and total (C) red palm weevils captured in STs over the 24 h diel cycle. Each circle represents 4, 16, and 19 weevils in A, B, and C, respectively.

Table 2. Summary of the time analyses of red palm weevil captures in STs.

	Male	Female	Total
N	73	267	340
Length of mean vector (radians)	0.488	0.398	0.415
Mean time ± SE (= mean vector)	11:15 ± 00:36	12:19 ± 00:23	12:03 ± 00:20
Concentration	1.116	0.868	0.911
Rayleigh test (*Z*)	17.40	42.38	58.44
Rayleigh test (*P*)	2.77×10^{-8}	$<1 \times 10^{-12}$	$<1 \times 10^{-12}$
95% confidence interval (lower & upper)	10:03 (150.954) & 12:26 (186.572)	11:32 (173.23) & 13:06 (196.603)	11:23 (170.969) & 12:43 (190.797)

al. (2014) found that the red palm weevil is strictly diurnal in Italy and Greece, whereas a few adults were captured immediately after sunset in Vietnam. Faleiro (2005) found that red palm weevil adults in Goa, India, were most active from 12 AM to 6 AM and least active between 6 AM and 12 PM. The inconsistencies among the previous studies and present results may be due to differences in location-specific factors, host species, or environmental factors. We suspect the main cause to be microclimatic differences among studies.

It is important to note that adult red palm weevils are internal borers and hence are not exposed to daylight conditions. Moreover, overlapping generations of red palm weevils can be found within the same palm trunk (Murphy & Briscoe 1999; Dembilio & Jacas 2012). The red palm weevil adults in this study were active mostly during the day, possibly because their activities were linked to plant volatiles emitted through the light-dependent reactions of photosynthesis or because the kairomones emanating from wounds in the host trees were more copious during the day. More comprehensive studies will be required to clarify why red palm weevil adults are diurnal.

The results revealed behavior differences between male and female red palm weevils. A number of previous studies have shown uneven sex ratios among trapped weevils, favoring females (Abraham et al. 1999; Faleiro & Satarkar 2003; Hoddle & Hoddle 2011; Hoddle et al. 2013). By contrast, Hallett et al. (1993) found no difference between the sexes in red palm weevil trapping trials conducted in Java and the United Arab Emirates. However, no previous study has demonstrated that the sex ratio of red palm weevil adults trapped in the field depends on the time of day. The diel pattern of the weevils trapped in the STs provides information about the differences in the daily activities of male and female red palm weevils. We found that the activity pattern of females was binomial, whereas that of males was not, although Fanini et al. (2014) found binomial activity patterns for both sexes. The mean time of male and female activity in the current study was 11:15 AM and 12:19 PM, respectively, suggesting that males initiate flight activity before females. Such behavior might be an adaptation for males to find a new and suitable host tree for future generations, after which the males produce an aggregation pheromone to attract females to visit the tree. Likewise, Fanini et al. (2014) found that male red palm weevils were active earlier in the day than females in both native and invasive localities, with mean times for males and females being 10:28 AM (male) and 1:57 PM (female) in Heraklion, Greece; 6:49 PM (male) and 6:48 PM (female) in Trapani, Italy; 3:08 PM (male) and 3:43 PM (female) in Catania, Italy; and 2:09 PM (male) and 2:35 PM (female) in Hoa Binh, Vietnam.

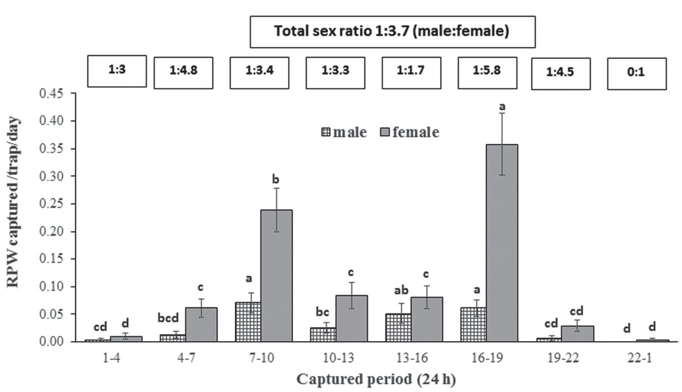

Fig. 4. Diel pattern for the mean total number of red palm weevils (RPW) captured per trap during the 62 d trapping period. Columns headed by the same letter are not significantly different from each other.

In conclusion, the use of ST traps can improve our understanding of red palm weevil behavior, which can be used to improve the timing of pest control strategies. Contact insecticides are likely to be most effective against red palm weevil adults when applied early in the morning or late in the evening, when the insects are most active.

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References Cited

Abraham VA, Faleiro JR, Prem Kumar T, Al-Shuaibi MA. 1999. Sex ratio of red palm weevil *Rhynchophorus ferrugineus* Olivier captured from date plantation of Saudi Arabia using pheromone traps. Indian Journal of Entomology 61: 201-204.

Abuagla AM, Al-Deeb MA. 2012. Effect of bait quantity and trap color on the trapping efficacy of the pheromone trap for the red palm weevil, *Rhynchophorus ferrugineus*. Journal of Insect Science 12: 120.

Ajlan A, Abdulsalam K. 2000. Efficiency of pheromone traps for controlling the red palm weevil *Rhynchophorus ferrugineus* Olivier (Coleoptera: Curculionidae), under Saudi Arabia conditions. Bulletin of the Entomological Society of Egypt (Economic Series) 27: 109-120.

AlAyedh HY, Aldryhim YN, Aldraihem OJ. 2013. Method and apparatus for capturing and time-sorting insects. U.S. 2013/0340319 A1, King Abdul Aziz City for Science and Technology, Riyadh, Saudi Arabia.

Alpizar D, Fallas M, Oehlschlager AC, Gonzalez LM, Chinchilla CM, Bulgarelli J. 2002. Pheromoe mass trapping of the West Indian sugarcane weevil and the American palm weevil (Coleoptera: Curculionidae) in palmito palm. Florida Entomologist 85: 426-430.

Çıtırıkkaya B, Tezcan S, Gülperçin N. 2014. A short note on non-target fauna collected by pheromone traps of the red palm weevil, *Rhynchophorus ferrugineus* (Olivier, 1790) (Coleoptera: Dryophthoridae) in İzmir Province of Turkey. Munis Entomology and Zoology 9: 792-794.

Dembilio O, Jacas J. 2012. Bio-ecology and integrated management of the red palm weevil, *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae), in the region of Valencia (Spain). Hellenic Plant Protection Journal 5: 1-12.

Faleiro J. 2005. Pheromone technology for the management of red palm weevil *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Rhynchophoridae)—a key pest of coconut. Technical Bulletin 4.

Faleiro J. 2006. A review of the issues and management of the red palm weevil *Rhynchophorus ferrugineus* (Coleoptera: Rhynchophoridae) in coconut and date palm during the last one hundred years. International Journal of Tropical Insect Science 26: 135-154.

Faleiro J, Satarkar V. 2003. Ferrugineol based pheromone lures for trapping red palm weevil, *Rhynchophorus ferrugineus* (Coleoptera: Rhynchophoridae) in coconut plantations. Indian Journal of Plant Protection 31: 84-87.

Fanini L, Longo S, Cervo R, Roversi P, Mazza G. 2014. Daily activity and non-random occurrence of captures in the Asian palm weevils. Ethology Ecology & Evolution. 26: 195-203.

Ferry M, Gomez S. 2002. The red palm weevil in the Mediterranean Area. Palms 46: 172-178.

Fiaboe K, Peterson AT, Kairo M, Roda A. 2012. Predicting the potential worldwide distribution of the red palm weevil *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae) using ecological niche modeling. Florida Entomologist 95: 659-673.

Greenhouse SW, Geisser S. 1959. On methods in the analysis of profile data. Psychometrika 24: 95-112.

Guarnieri A, Maini S, Molari G, Rondelli V. 2011. Automatic trap for moth detection in integrated pest management. Bulletin of Insectology 64: 247-251.

Hallett R, Gries G, Gries R, Borden J, Czyzewska E, Oehlschlager A, Pierce H, Angerilli N, Rauf A. 1993. Aggregation pheromones of two Asian palm weevils, *Rhynchophorus ferrugineus* and *R. vulneratus*. Naturwissenschaften 80: 328-331.

Hallett RH, Oehlschlager AC, Borden JH. 1999. Pheromone trapping protocols for the Asian palm weevil, *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae). International Journal of Pest Management 45: 231-237.

Hoddle MS, Hoddle CD. 2011. Evaluation of three trapping strategies for red palm weevil, *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae) in the Philippines. Pakistan Entomology 33: 77-80.

Hoddle MS, Al-Abbad AH, El-Shafie HAF, Faleiro JR, Sallam AA, Hoddle CD. 2013. Assessing the impact of areawide pheromone trapping, pesticide applications, and eradication of infested date palms for *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae) management in Al Ghowaybah, Saudi Arabia. Crop Protection 53: 152-160.

Inghilesi AF, Mazza G, Cervo R, Gherardi F, Sposimo P, Tricarico E, Zapparoli M. 2013. Alien insects in Italy: comparing patterns from the regional to European level. Journal of Insect Science 13: 73.

Ju R-T, Wang F, Wan F-H, Li B. 2011. Effect of host plants on development and reproduction of *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae). Journal of Pest Science 84: 33-39.

Kovach WL. 2011. Oriana—Circular Statistics for Windows. Kovach Computing Services, Pentraeth, Wales, United Kingdom.

López O, Rach MM, Migallon H, Malumbres MP, Bonastre A, Serrano JJ. 2012. Monitoring pest insect traps by means of low-power image sensor technologies. Sensors 12: 15801-15819.

Madden L, Knoke J, Louie R. 1982. Considerations for the use of multiple comparison procedures in phytopathological investigations. Phytopathology 72: 1015-1017.

Manachini B, Billeci N, Palla F. 2013. Exotic insect pests: the impact of the red palm weevil on natural and cultural heritage in Palermo (Italy). Journal of Cultural Heritage 14: e177-e182.

Murchie A, Burn D, Kirk W, Williams I. 2001. A novel mechanism for time-sorting insect catches, and its use to derive the diel flight periodicity of brassica pod midge *Dasineura brassicae* (Diptera: Cecidomyiidae). Bulletin of Entomological Research. 91: 199-203.

Murphy S, Briscoe B. 1999. The red palm weevil as an alien invasive: biology and the prospects for biological control as a component of IPM. Biocontrol News and Information 20: 35N-46N.

Potamitis I, Rigakis I, Fysarakis K. 2014. The electronic McPhail trap. Sensors 14: 22285-22299.

Reddy G, Fettköther R, Noldt U, Dettner K. 2005. Capture of female *Hylotrupes bajulus* as influenced by trap type and pheromone blend. Journal of Chemical Ecology 31: 2169-2177.

Rochat D, González AV, Mariau D, Villanueva AG, Zagatti P. 1991. Evidence for male-produced aggregation pheromone in American palm weevil, *Rhynchophorus palmarum* (L.) (Coleoptera: Curculionidae). Journal of Chemical Ecology 17: 1221-1230.

SAS. 2009. Base SAS® 9.2 Procedures Guide. SAS Institute Inc., Cary, North Carolina, USA.

Stevenson DE, Coble C, Harris MK. 2006. A clockwork trap for detecting circadian rhythms in insects. Southwestern Entomologist 31: 69-74.

Vacas S, Primo J, Navarro-Llopis V. 2013. Advances in the use of trapping systems for *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae): traps and attractants. Journal of Economic Entomology 106: 1739-1746.

Vacas S, Abad-Payá M, Primo J, Navarro-Llopis V. 2014. Identification of pheromone synergists for *Rhynchophorus ferrugineus* trapping systems from *Phoenix canariensis* palm volatiles. Journal of Agricultural and Food Chemistry 62(26): 6053-6064.