Effects of Trap Locations, Pheromone Source, and Temperature on Red Palm Weevil Surveillance (Coleoptera: Dryophthoridae)

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Effects of trap locations, pheromone source, and temperature on red palm weevil surveillance (Coleoptera: Dryophthoridae)

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Abstract

Pheromone traps play a crucial role in the integrated pest management of the red palm weevil, *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae). The objective of this study was to increase the effectiveness of pheromone traps by evaluating the effects of location, temperature, degree of palm fruit fermentation, and pheromone lure source on red palm weevil capture rates. Traps baited with either Ferrolure or Rhylure were positioned in 3 rows and checked twice per wk for 12 wk starting 20 Apr 2019. Overall weekly capture rate per trap varied from 1.25 to 9.00. Those traps that were placed in the shade near infested date palm trees in areas of relatively high soil moisture captured more red palm weevil (9 adults per trap per wk) than traps exposed to direct sunlight (1.25 adults per trap per wk). Additionally, traps placed at the field edge captured more adults than those in the middle of the field. Capture rates were highly negatively correlated with temperature. Ferrolure traps captured significantly more red palm weevils than Rhylure traps. The sex ratio of captured weevils in all traps was female-biased. Results obtained from Y-tube olfactometer assays indicated that the response of red palm weevil adults to 5- and 8 d old fermented date fruits were relatively high (86.7–100%). In kairomone field tests more red palm weevil adults were attracted to traps with 8 d fermented date fruits compared with 5 d old. Our results indicated that placing traps containing Ferrolure, water, and kairomones in red palm weevil preferred sites near the edges of the orchard in moderate air temperatures (22–33 °C) increased the efficacy of pheromone traps.

Key Words: *Rhynchophorus ferrugineus*; kairomones; Ferrolure; Rhylure; date palms

Resumen

Las trampas de feromonas juegan un papel crucial en el manejo integrado de la plaga del picudo rojo de las palmeras, *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae). El objetivo de este estudio fue aumentar la efectividad de las trampas de feromonas mediante la evaluación de los efectos de la ubicación, la temperatura, el grado de fermentación del fruto de la palma y la fuente de atracción de feromonas en las tasas de captura del picudo rojo. Las trampas cebadas con Ferrolure o Rhylure se colocaron en 3 filas y se revisaron dos veces por semana durante 12 semanas a partir del 20 de abril del 2019. La tasa de captura semanal general por trampa varió de 1,25 a 9,00. Las trampas que se colocaron a la sombra cerca de palmeras datileras infestadas en áreas con humedad del suelo relativamente alta capturaron más picudos rojos de las palmeras (9 adultos por trampa por semana) que las trampas expuestas a la luz solar directa (1,25 adultos por trampa por semana). Además, las trampas colocadas en el borde del campo capturaron más adultos que las que estaban en el medio del campo. Las tasas de captura se correlacionaron muy negativamente con la temperatura. Las trampas de Ferrolure capturaron significativamente más picudos rojos de las palmeras que las trampas de Rhylure. La proporción de sexos de los gorgojos capturados en todas las trampas fue sesgada por las hembras. Los resultados obtenidos de los ensayos con el olfatómetro de tubo en forma de "Y" indicaron que la respuesta de los adultos del picudo rojo de la palma a los frutos de dátiles fermentados de 5 y 8 dias de edad fue relativamente alta (86,7–100%). En las pruebas de campo con kairomona, más adultos del picudo rojo de las palmeras se sintieron atraídos por trampas con frutos de dátiles fermentados de 8 días en comparación con los de 5 días de edad. Nuestros resultados indicaron que la colocación de trampas que contienen Ferrolure, agua y kairomonas en los sitios preferidos por el picudo rojo de las palmeras cerca de los bordes del huerto en temperaturas del aire moderadas (22–33 °C) aumentó la eficacia de las trampas de feromonas.

Palabras Clave: *Rhynchophorus ferrugineus*; kairomonas; Ferrolure; Rhylure; palmeras datileras

The red palm weevil, *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae), is a persistent pest that causes substantial losses of date, coconut, and ornamental palm crops in many Asian, African, and European countries (FAO 2019). The red palm weevil is also a serious threat as an invasive (Audsley et al. 2017); its cryptic behavior (Giblin-Davis et al. 2013; Mahmud et al. 2015; Pontikakos et al. 2017) allows it to enter uninfested areas undetected (Dembilio & Jaques 2015; Al-Dosary et al. 2016). Additionally, recommended management measures have not been effective in controlling red palm weevil outbreaks (FAO 2019; Rasool et al. 2020).

Pheromone traps are a major component of integrated pest management programs for the control of red palm weevil. Traps are used

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for surveillance, mass trapping, and control program evaluations (Jaques et al. 2017; Suma et al. 2017; FAO 2020). However, discrepancies appear in the literature regarding the efficiency of pheromone traps. Adult red palm weevil field populations were reduced by 70 to 80% when mass trapping was used at a density of 1 to 3 traps per ha (Muralidharan et al. 1999; Oehlschlager 2006). However, population reduction was not achieved in similar field trials conducted in Spain (Jaques et al. 2017). In another study, Al Ansi et al. (2020) reported that only 25% of tagged adults were attracted to pheromone traps. Pheromone trap placement is equally as important as other factors for improving catch efficiency. Placing pheromone traps on the ground away from small palms provides a landing area for red palm weevils (FAO 2019). Additionally, pheromone traps positioned on the ground close to coconut palm trunks have been shown to be very attractive to these weevils because they provide a favorable shade (Azmi et al. 2014). Moreover, trap placement in the shade increased pheromone longevity to more than 3 mo (Hallett et al. 1999). Hallett et al. (1999) also found that traps installed at ground level captured more red palm weevil adults than those installed 5 m above the ground. Because of the serious threat of red palm weevil to date palms, there has been interest recently in understanding why pheromone traps do not trap adults effectively. Therefore, the objective of this study was to increase the effectiveness of pheromone traps by evaluating the effect of trap placement in specific sites, determining the ideal temperature for trapping, assessing the efficacy of fermented date palm as a kairomone, and finally investigating the effect of some commercial pheromone lures on capture rates of red palm weevil.

Material and Methods

STUDY AREA

The field study was conducted at the Altholaima commercial date orchard (24.768666°N, 46.536500°E) located in Ad Diriyah Governorate, West of Riyadh, Kingdom of Saudi Arabia. Experimental trials were performed between 20 Apr and 22 Jul 2019. The orchard is approximately 35 ha, containing approximately 1,700 *Phoenix dactylifera* L. (Arecaceae) date palm trees of various varieties and ages (5–25 yr old). Date fruit is the primary crop in this orchard, but lemons, grapes, olives, and pomegranates also have been planted. Shrubs and weeds of different species were growing among the crops. Active red palm weevil infestations were present throughout the orchard.

PHEROMONE LURES AND ODOR ATTRACTANTS

Two sources of pheromone lures were used in the study. The first was Ferrolure+™, ferrugineol (9 parts 4-methyl-5-nonanol; 1 part 4-methyl-5-nonanone; purity > 98%), applied at a concentration of 700 mg per lure, with a release rate of 3 to 10 mg per d (ChemTica International, S.A., San Jose, Costa Rica). The second lure was Rhylure-700, ferrugineol (9 parts 4-methyl-5-nonanol; 1 part 4-methyl-5-nonanone; purity 98%), applied at a concentration of 700 ± 50 mg per lure, with a release rate of 3.5 to 10 mg per d (Russell IPM Ltd., Flintshire, United Kingdom).

Additionally, a kairomone was prepared from date fruits of the 'Sukari' variety. Dates were fermented in water for 2 d at room temperature prior to placement in traps. Ten fermented dates were added to each trap along with 1.5 L water.

TRAPS

Five-liter bucket traps (Oehlschlager et al. 1993) modified in Kingdom of Saudi Arabia by the Ministry of Environment, Water, and Agriculture (Anonymous 1994) with 4 side openings were used. Fifteen traps were buried in the ground up to the level of the side openings (about 20 cm). Three treatments were used: (1) Ferrolure traps, deployed with Ferrolure+™ lure, kairomones mixture; (2) Rhylure traps, loaded with Rhylure-700 lure, kairomone mixture; and (3) dry traps, containing Rhylure-700 lure only. Traps were distributed randomly in 3 parallel rows on the eastern and western edges of the study area as well as in the middle of the field. Distance between rows was 70 m and between traps within a row was 60 m. The site descriptions (for each trap) are provided in Table 1.

Trapped weevils were collected after 5 and 8 d of fermentation. On d 8, the dates and water were replaced with new 2-d fermented dates and water. This cycle was continued until the end of the study. Ad Diriyah air temperatures were collected from AccuWeather (AccuWeather 2019).

OLFACTOMETER ASSAY

Attractive response of female and male red palm weevils (n = 60) to 5 and 8 d of fermented palm date fruit was tested in the laboratory using a glass Y-tube olfactometer (Analytical Research Systems Inc., Gainesville, Florida, USA) following a procedure similar to that described by Soffan et al. (2016). Adult red palm weevils were starved overnight (12 h) prior to testing. Test materials consisting of a 10 µL of solution of fermented dates on filter paper were placed in one arm

Table 1. Microhabitat descriptions of trap placements and mean number of captured weevils (± SE) per trap per wk in traps baited with Ferrolure and Rhylure pheromone lures. Means in the same column for the same lure source marked with different lower case letters are significantly different (LSD at $P < 0.05$). The total capture rate means in the last row marked with different capital letters are significantly different (LSD at $P < 0.05$).

	Ferrolure traps		Rhylure traps	
Trap No.	Mean ± SE	Microhabitat description	Mean ± SE	Microhabitat description
1	6.33 ± 0.77 a	shade, close to palm tree 1.50 m, moist soil	5.50 ± 0.37 a	shade, close to palm tree 1.50 m, close to 2 infested palm trees, moist soil
2	1.58 ± 0.17 b	exposed to sunlight, many grasses around	5.50 ± 0.32 a	shade, close to palm tree 2 m apart, close to 2 infested palm trees, moist soil
3	9.00 ± 0.57 a	shade, close to palm tree at distance 50 cm, later infested palm detected in surrounded area, moist soil	4.00 ± 0.35 ab	shade, close to lemon tree, the nearest palm tree was at distance of 5 m, moist soil
4	2.83 ± 0.30 b	close to fig tree 1.5 m	1.25 ± 0.23 c	exposed to sunlight, many grasses around
5	8.00 ± 0.41 a	shade, close to palm tree 1.5 m, later infested palm was detected at distance 12 m, moist soil	2.92 ± 0.18 bc	exposed to sunlight, many grasses around, and some citrus and fig trees nearby
Total mean	5.55 ± 0.30 A		3.83 ± 0.17 B	

while the remaining arm served as a control. Individual male and female red palm weevils were released one at a time within the first cm of the base tube of the olfactometer, and their responses were observed for 10 min. The response was recorded as 'no-choice' if adults stayed in the main tube and 'choice' if they entered one of the arms. The residence time (waiting period and movement time to reach the end of the arm) was recorded. Individuals that did not choose a particular arm were excluded from statistical analysis. Each individual was tested once. Between experiments, all parts of the Y-tube were cleaned with acetone. The odor source was replaced by changing the filter paper.

STATISTICAL ANALYSES

Before the analysis, mean weevil capture data were transformed by log (y + 1) to normalize the data then subjected to ANOVA (GLM procedure) and Fisher's least significant difference using SAS 9.2 (SAS 2008) software. All trap data are presented as mean ± standard error (SE). A linear correlation was used to analyze the relationship between daily temperature and weevil trap capture rate. The olfactometer assay data were analyzed using the Chi-square (Sokal & Rohlf 1995). Differences in all analyses were considered significant at $P < 0.05$.

Results

INFLUENCE OF LOCATION ON CAPTURE RATE

Red palm weevil abundance was highest in Ferrolure traps placed in shade, close to date palm trees, or on ground with high moisture content (i.e., close to an irrigation site) compared with traps located in direct sunlight (Table 1). Trap number 3 captured more red palm weevil, likely because it was close to a known infested palm tree. Similar trends were observed in the Rhylure traps.

Trap location also affected abundance in traps; those installed in the eastern and western rows near the internal edge of the field captured significantly more red palm weevil adults ($F = 7.63$; df = 2, 11; $P = < 0.0001$) than traps in the middle row, regardless of the pheromone lure source. The mean number of captured adults per trap per wk in the eastern and western rows were 4.28 and 3.83, respectively, significantly higher than the mean abundance of 1.78 in the middle row (Fig. 1). Capture rates in the eastern and western rows did not differ significantly (Fig. 1).

The number of captured red palm weevil adults decreased with increasing ambient temperature (Fig. 2). Regardless of the pheromone lure source, the capture rate was highly negatively correlated with

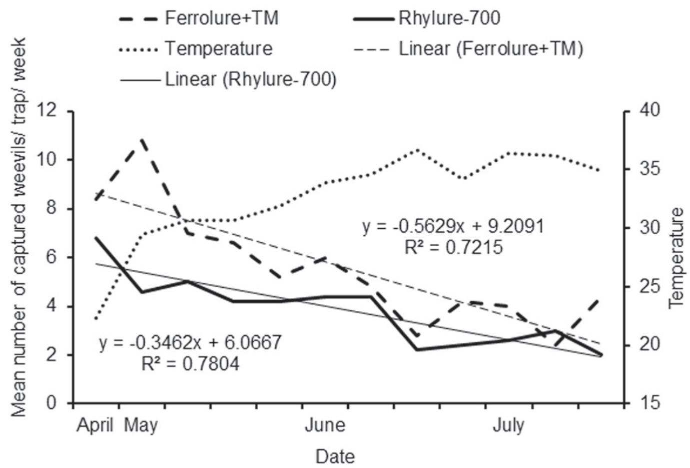

Fig. 2. Mean temperature and mean number of captured weevils per trap per wk in Ferrolure and Rhylure traps.

temperature ($R = -0.88$, and $P = 0.0002$). The correlation coefficients for Ferrolure traps and Rhylure traps were $R = -0.79$ ($P = 0.002$) and $R = -0.87$ ($P = 0.0002$), respectively.

Pheromone lure source also had an effect on the trap abundance. The total number of adults captured during the study was 593. The Ferrolure traps captured 333 adults, whereas the Rhylure traps captured 230 adults, and the dry traps captured only 31 adults. The mean number of captured weevils per trap per wk was significantly higher ($F = 32.25$; df = 2, 4; $P = < 0.0001$) in the Ferrolure traps than the Rhylure traps and dry traps (Fig. 3). The sex ratio of captured weevils was biased toward females. The mean sex ratio from all treatments was 2.5 females to 1.0 male. The female ratio in Rhylure traps was higher than that of the Ferrolure traps (Fig. 3).

EFFECT OF DATE FERMENTATION TIME ON TRAP CAPTURE

The field study showed that traps with 8 d old kairomone (fermented date fruits) captured more red palm weevil adults than the 5 d old; however, the difference was not significant ($F = 5.05$; df = 1, 4; $P = 0.71$). The mean number of red palm weevils captured per wk in both Ferrolure and Rhylure traps with 5 d old kairomone was slightly less than in 8 d old kairomone (Fig. 4). Traps with 5 d old kairomone showed significantly ($F = 2.86$; df = 3, 4; $P = < 0.0006$) different capture rates with different lure sources (Fig. 4).

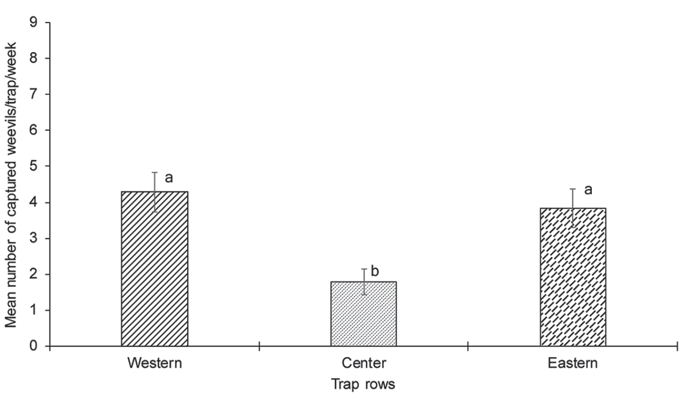

Fig. 1. Mean number (± SE) of captured weevils per row per wk. Bars marked with different letters are significantly different (ANOVA, GLM procedure, followed by LSD at $P < 0.05$).

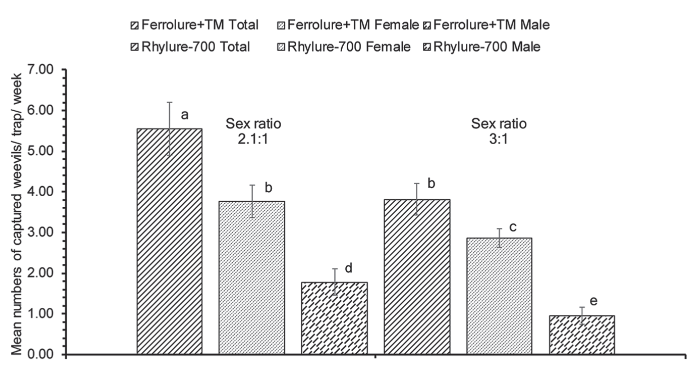

Fig. 3. Mean number of captured male and female red palm weevils (± SE) per trap per wk in Ferrolure and Rhylure traps. Bars marked with different letters are significantly different (ANOVA, GLM procedure, followed by LSD at $P < 0.05$).

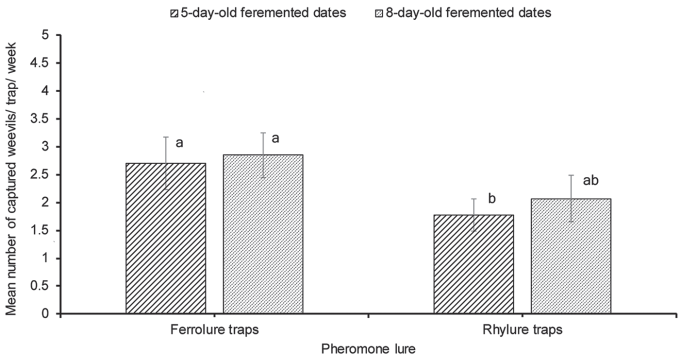

Fig. 4. Mean number of captured red palm weevils (± SE) using 5 and 8 d fermented dates as kairomones. Bars marked with different letters are significantly different (ANOVA, GLM procedure, followed by LSD at $P < 0.05$).

OLFACTOMETER ASSAYS

More female (100%) than male (92.3%) weevils were attracted to 5 d fermented dates ($\chi^2 = 11.5$; $P = 0.0007$). The response of males to 8 d fermented date fruits was significantly greater than that of females ($\chi^2 = 13.5$; $P = 0.0002$) (Table 2). The waiting time before moving from the base of Y-tube for females (5.82 and 12.38 s, respectively) was less, but not significantly different ($P = 0.08$ for 5 d and $P = 0.44$ for 8 d) than those for males (13.5 and 17.08 s, respectively) for either d. The residence times within the Y-tube were not significantly different among male and female red palm weevils ($P > 0.05$) (Table 2).

Discussion

Earlier studies using pheromone traps for integrated pest management of red palm weevil focused on lure sources and pheromone release rates (Faleiro & Chellapan 1999; Kumar et al. 2004), trap design (Hallett et al. 1999), trap color (Abuagla & Al-Deeb 2012; Ávalos & Soto 2015), number of traps per ha (Faleiro et al. 2011), and kairomones (Hallett et al. 1993). The current study focused on the impact of trap locations (edge or middle of the palm orchard), ambient temperature, and the degree of date fruit fermentation (as kairomones) on abundance in pheromone traps. The measurement of these parameters will provide valuable information for improving the efficiency of red palm weevil pheromone trapping in date palm orchards.

The pheromone lure source affected the trap capture rates. Ferrolure traps captured more adults than those containing Rhylure. However, the efficacy of 4 commercial lures (including both lures used in the current study) concluded that commercially available lures were equally effective at attracting red palm weevil adults in the field and laboratory tests (El-Shafie & Faleiro 2017). Additionally, no significant differences between lures were found in the number of red palm weevils captured per wk when 3 commercial pheromone lures (Ferrolure+™, RHYFER™, and RHYNCAP™) were used (Abdel-Azim et al. 2017). Furthermore, we discovered that relatively more females than males were attracted to the traps and volatiles in the Y-tube olfactometer tests. This may be due to the fact that red palm weevil females have more olfactory sensilla on their antennae (Avand-Faghih 2004). In addition, field activity was reported to be higher among females than males (Al Ansi et al. 2020). Also, the trap capture rate of females was higher than males (Chakravarthy et al. 2014; Al Ansi et al. 2020). The preferential red palm weevil female attraction to the pheromone may be attributed to more pressure on females to disperse in search of mates, food resources, and oviposition sites (Soroker et al. 2005). It has been suggested that pheromone lures serve as long-range attractants, whereas kairomones act as short-range attractants, encouraging the weevil to enter the trap (Jaffé et al. 1993).

Furthermore, several commercial companies have produced synthetic aggregation pheromones to attract red palm weevil with varied success. The efficacy of 4 commercial aggregation pheromones was evaluated in the field and no significant differences in their ability to attract red palm weevils were shown (El-Shafie & Faleiro 2017). Similarly, 3 pheromone lures (Ferrolure+™, RHYFER™, and RHYNCAP™) were evaluated, revealing that all tested lures equally attracted red palm weevil adults (Abdel-Azim et al. 2017).

Our results demonstrated that the sex ratio of trapped red palm weevil was biased toward females regardless of the pheromone lure source. The results obtained are in agreement with the results of many researchers (Soroker et al. 2005; Aldryhim & Al Ayedh 2015; Ávalos & Soto 2015).

Kairomones play a role in communication between different species such as some plant parts (Bakthavatsalam 2016) and have a main role in pest management approach especially for cryptic insects (Soroker et al. 2015). The current study showed that traps with 8 d old kairomone (fermented date fruits) captured more red palm weevil adults than the 5 d old. Many pheromone trap studies have recommended the use of kairomones such as date fruits (Al Saoud 2006; Abdel-Azim et al. 2017; Abbass et al. 2019) to attract red palm weevil to pheromone traps (Faleiro & Chellapan 1999; Hallett et al. 1999; Faleiro & Satarkar 2003; Oehlschlager 2007). The efficacy of volatiles from dates, palm stems, and molasses (Vacas et al. 2017) as kairomones to enhance red palm weevil attraction to pheromone traps has been demonstrated (Poorjavad et al. 2009; Venugopal & Subaharan 2019). Several food baits in red palm weevil pheromone traps have been tested and it was found that fast-fermented date fruits were most effective, capturing more adults than other items, such as palm stem pieces and sugarcane (Abdel-Azim et al. 2017). The quantities of date fruits used as kairomones in pheromone trap studies varied from 200 to 500 g (Abbas et al. 2006; Al Saoud 2006; Al-Saoud & Ajlan 2013; Hoddle et al. 2013; Abdel-Azim et al. 2017; Abbass et al. 2019).

Our results show that wet traps captured more adults (> 230) than dry ones (31). The red palm weevil adults tend to be attracted to water and wet areas (Aldryhim & Khalil 2003). Additionally, it was found that

Table 2. Adult red palm weevil responses to 5 and 8 d old fermented dates in a Y-tube olfactometer assay. Values bearing the same letter in the same column are not significantly different (LSD at $P < 0.05$).

Degree of fermentation	Sex	% Response	Residence time in seconds: Waiting	Movement	Total
5 d old	female	100	05.82 ± 2.56 a	53.27 ± 11.03 a	59.09 ± 11.97 a
	male	92.3	13.50 ± 4.21 a	52.83 ± 19.62 a	66.33 ± 20.07 a
8 d old	female	86.7	12.38 ± 4.47 a	56.77 ± 10.40 a	69.15 ± 12.74 a
	male	92.3	17.08 ± 6.62 a	73.42 ± 24.56 a	90.50 ± 29.60 a

red palm weevil infested more palm trees in flood-irrigated plots than drip-irrigated plots in the same orchard (Aldryhim & Al-Bukiri 2003). It also has been reported previously that wet pheromone traps captured more red palm weevil adults than dry traps, so the addition of water to pheromone traps is crucial for increasing efficiency (Vacas et al. 2013). Red palm weevil adults hide in the base of palm leaves (fronds), which are shaded and humid (Abraham et al. 1998). Also, pheromone lures maintained effectiveness longer in shaded areas (Faleiro et al. 1999). Furthermore, the addition of fermentation plant materials to pheromone traps was shown to enhance the attraction of red palm weevils (Oehlschlager 2016), which is consistent with our olfactometer assay findings.

Trap location substantially affected trap capture abundance. Those that were installed in shaded areas close to infested palm trees with moist soil had the highest mean capture rates per wk. We found that traps deployed in habitats with direct sunlight exposure captured the least number of weevils per wk. This is likely due to the behavioral traits of adult red palm weevils, which seek out cavities in infested tree trunks with high moisture content and little sunlight exposure (Aldryhim & Al-Bukiri 2003).

Traps that were installed on the edge rows (eastern and western rows) captured more adults than traps placed in the middle rows. We also observed more infested palm trees at the orchard edges compared to the middle rows. This result is consistent with reported data that pheromone traps positioned on the edges of oak woodland blocks captured more oak processionary moths than traps positioned within the oak woodland itself (Williams & Jonusas 2019). In coconut black-headed caterpillar, *Opisina arenosella* Walker (Lepidoptera: Xyloryctidae), pheromone trap placement either at the border or center of the orchards depends on the pest density within the field and also on their migratory behavior (Muniyappa et al. 2018). Additional investigations are required to clarify the effects of placement on the edges or center of palm orchards on the efficiency of pheromone traps for red palm weevil. Additionally, it is not clear whether adults are attracted from adjacent palm orchards.

The red palm weevil capture rate was correlated with temperature. Interestingly, the maximum temperature recorded during this study was beyond the known range favored by red palm weevil (Fig. 2). The air temperatures between 18.5 °C and 36 °C are favored for dispersal, with an optimum of 30 to 34 °C (Rochat et al. 2017). The average temperature of infested date palm tissue was 32.60 °C with a range of 25.03 to 37.39 °C (Mozib & El-Shafie 2013). We observed a negative correlation between temperature and capture rate, which was consistent with previous findings (Al-Asfoor 2012; Aldryhim & Al Ayedh 2015). In contrast, a positive correlation between capture rate and average temperature over 2 yr was reported (El-Lakwah et al. 2011).

The potential relationship between weevil capture rates and temperature also has been evaluated using correlation analysis. Results varied among studies; some researchers have reported that the number of captured weevils was negatively correlated with temperature (Faleiro & Satarkar 2005; Aldryhim & Al Ayedh 2015), whereas others report that the capture rate was positively correlated with average temperature (El-Lakwah et al. 2011; Huang 2013; Firdaus et al. 2020).

The behavioral responses of insects to attractants have been investigated using olfactometer assays. The effects of different dosages of ferrugineol pheromone on virgin and mated red palm weevil males and females were evaluated (Poorjavad et al. 2009). The results revealed that the responses of males and females to the aggregation pheromone increased with mating, and the mated females were highly responsive to ferrugineol. An olfactometer assay to determine the response of adult female red palm weevils to volatiles emitted from fresh palm tissue of 7 date palm cultivars was used, and the results showed that the 'Khalas' cultivar was the preference and recorded a high degree of attraction to red palm weevil (Faleiro et al. 2014). The response of red palm weevil to 31 natural plant volatile oils, 18 terpenes, and 9 chemical compound volatiles using an olfactometer was assayed, and the results revealed that some of the tested volatiles were either attractants or repellents for both sexes (Sharaby & Al-Dosary 2014). Also, an olfactometer was used to evaluate red palm weevil responses to ferrugineol; where both sexes of red palm weevil adult virgins were highly responsive to the aggregation pheromone, but the response decreased with age and mating (El-Shafie & Faleiro 2017). Host attractants for red palm weevil using an olfactometer were assayed and it was found that a mixture of compounds was more effective than single compounds (Gunawardena et al. 1998).

Our results indicate that trap efficiency could be significantly increased by selecting trap locations that are shaded, moist, and close to infested trees, installing traps at the edges of date palm orchards, and increasing the number of traps during moderate air temperature ranges (22–33 °C).

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