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First use of radio telemetry to assess behavior of red palm weevil, *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Dryophthoridae) in the presence and absence of pheromone traps

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ABSTRACT

The red palm weevil, *Rhynchophorus ferrugineus* (Olivier) (RPW) is a destructive insect pest of palm trees, destroying thousands of date palm trees in Kingdom of Saudi Arabia (KSA) and other countries. Radio telemetry has provided beneficial knowledge on the movements, the habitat preference, and reproductive behaviors of numerous species of animals. In this study, we tracked the movements and habitat preferences of RPW in date palm orchards in KSA using radio telemetry with and without the use of pheromone traps. This study is the first to track individual adult RPW using radio telemetry in production date palm orchards. Small radio transmitters (LB-2X, HOLOHIL) were glued on wild-caught adults and released in date palm orchard in late April and early May 2019. Our results indicated that wild-caught adult RPW with attached dummy transmitters were able to fly normally, whereas laboratory-reared adults were unable to fly successfully with attached transmitters. The flight behavior of the RPW adults was influenced by pheromone traps. The average flight of the RPW was 69.1 m (7.7–213 m) in the presence of pheromone traps and only 24.4 m (10–90 m) without pheromone traps. The mean distances females and males covered were 95.80 m and 42.40 m in the presence of pheromone traps and 32.47 m, 16.30 m in the absence of pheromone traps, respectively. The percentages of tagged adults that dispersed more than 50 m were 50% and 8.3% in the presence and absence of pheromone traps, respectively. Time required for taking-off from the release point was 5–20 min and 0.5–6 h in the presence and absence of pheromone traps, respectively. The aggregation rate was 33.3% and 75.0%, in the presence and absence of pheromone traps, respectively. Only a single flight was taken by each adult in the presence or absence of pheromone traps. Adults showed high preference in selecting habitats. RPW adults were attracted to infested or previously infested male palm trees, surface water of drip irrigation systems, and pheromone traps. In conclusion, radio telemetry appears to be a suitable technique to track RPW in date palm orchards when wild-caught adults are used.

1. Introduction

The red palm weevil (RPW) *Rhynchophorus ferrugineus* (Olivier, 1790) (Coleoptera: Dryophthoridae) is a destructive palm tree insect. RPW is a cryptic pest (Dembilio et al., 2010) spending all life stages in the trunk of palm trees (Abraham et al., 1998; Aldryhim and Ayedh, 2015; Ali-Bob, 2019; Dembilio et al., 2010; Anon., 1998), making early detection of an infestation challenging and therefore difficult to control (Fiaboe et al., 2012). This cryptic behavior apparently protects RPW from harsh external climatic environments, allowing the persistence of this pest in a wide range of geographical areas and environments (Murphy and Briscoe, 1999). Local and international trade of young palm offshoots, which are infested with non-detected RPW, has facilitated the spread of this pest into uncontaminated regions (Potamitis and Rigakis, 2015).

The behavior of dispersal is a crucial feature of an insect life history (Bonte and Dahirel, 2017). Information on the flight behavior of insect pests is needed for more effective implementation of integrated pest management approaches (Osborne et al., 2002). Tracking the dispersal of insects has been studied by several methods. Kissling et al. (2014) reviewed tracking methods available for insects such as harmonic-radar systems, radio telemetry (RT), and radio frequency identification (RFID).

Radio telemetry (RT) has provided beneficial knowledge on the movements, habitat preference, and reproductive behavior of numerous species of animals (Gutema, 2015). During the last three decades, the size of radio transmitters has become small enough to be used in tracking small animals (Hedin and Ranius, 2002). Therefore, RT has become a suitable method for tracking insect movement and is especially useful for penetrating dense vegetation and detecting longer wavelength signals (Hedin and Ranius, 2002). The major advantage of the RT method is the potential of using different frequencies to track and identify individuals in the same area and at the same time (Riecken and Raths, 1996). The RT is relatively inexpensive (Markov and Markov, 2005). The RT technique has been used to track numerous insect species belonging to different insect orders (Kissling et al., 2014).

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Only a single study is available using RT to track RPW in screen cages (2.5 × 2.5 × 3 m) under greenhouse conditions (Hamidi et al., 2017).

A review of the literature indicated that no studies have been conducted to use advance technologies similar to RT to track the adult RPW under field conditions. Tracking data may provide useful information on the dispersal behavior and habitat preference of adult RPW. This data will be useful for implementing pest management programs for the control of the RPW. The objective of our study was to track the movement of RPW adults by using RT in the absence and presence of pheromone traps in a date palm orchard located in the Kingdom of Saudi Arabia (KSA).

2. Materials and methods

2.1. Study area

The study was conducted at the 1000 ha Nafa Farm located in Al Kharj Governorate, 80 km southeast of Riyadh, KSA. One block (24°13′29.6″N 47°14′38.9″E, 441 m altitude) of date palm trees, *Phoenix dactylifera* L., with 650 individual trees were used. Drip irrigation was used and there was no understory vegetation.

2.2. Materials:

We used radio transmitters (LB-2X, HOLOHIL® Systems Ltd, Ontario, Canada, http://www.holohil.com) with a weight of 0.28 g, 8 × 4 × 2.8 mm, including a 140-mm long antenna and with a frequency range 150–151 MHz band. The battery had a nominal life of approximately 12 days per manufacturer. The transmitter pulse rates ranged from 0.55 s^{-1} to 0.61 s^{-1}. Iron soldering (Soldering Irons, Taiyo Electric Ind. Co., Ltd. Japan) was used to activate transmitters. Super glue (Altico Chemical Pte Ltd, Indonesia) was used to fix transmitter on the pronotum of each weevil.

Radio receiver (TRX-2000S, Wildlife Materials, and Carbondale, Illinois, USA) was used to detect transmitter frequencies with a capacity to scan up to 400 radio signals on two full frequencies of pre-programmed frequencies. A Yagi antenna (Yagi three elements; Wildlife Materials Inc., Murphysboro, Illinois, USA) was connected to the receiver. Headphone were linked to the receiver to pick up the sound of the transmitter signals. The system was calibrated by collecting signals from four directions; the antenna was positioned to the South. The radio transmitter was moved in the four direction from the antenna, while the antenna on the fixed position. Fig. 1. Shows the respond of the transmitter from each direction. Fig. 2 shows the signals from the transmitter.

Global Positioning System (GPS) (Montana 650, Garmin International, Inc. Kansas, USA), thermo-hygrometer (Omega Engineering, Inc. OM-EL-USB-2-LCD, USA), anemometer (Lutron AM-4201 Digital Anemometer, Taiwan), and meter wheel were also used in the current study. A metal platform (height 150 cm, the base 20 × 20 cm) was used as a release point.

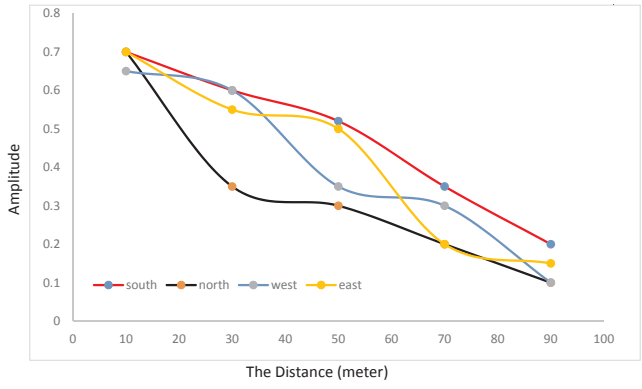

Fig. 1. The response of the transmitter with the position changes of Antenna.

2.3. Methods

A preliminary field study was conducted to evaluate the flight ability of the adult weevil equipped with a dummy transmitter of same weight and size of the RT. Three groups of adult weevils were used. The weevils of the first group were laboratory-reared adults; the second group was collected as adults from the field and was maintained for two weeks in the laboratory (considered partially-reared), the third group was wild-caught adults collected from traps and fed on sugar cane for only 24 h. Each group included ten adults. Adults were released in the field on the platform. Flight ability was recorded for each adult.

Two tracking experiments were conducted in late April and early May 2019 where adult weevils are most active between March and May (Abraham et al., 1998). The first experiment was conducted without pheromone traps, whereas the second experiment used pheromone traps. Adult male and female RPW were collected from infested palm orchards 24 h prior to the experiments, and were fed on sugar cane for 24 h, and the body weight recorded for each adult.

In the first experiment, radio transmitters were attached to six females and six males and released from the platform at a height of 1.5 m in the center of the selected block (Fig. 3). Due to the diurnal activity of RPW (Fanini et al., 2014; Aldryhim and Al Ayedh, 2015), tagged adults were tracked at three hour intervals from 4:30 am to 7:30 pm daily by using the Yagi antenna connected to a radio receiver until the signal of the transmitter was undetectable. The sunrise and sunset occurred at 5:30 am and 6:15 pm, respectively. GPS was used to locate the position of each tagged adult for each reading. Moving distance was measured by using a wheel meter (Fig. 3).

The second experiment was the same as the first experiment but pheromone traps were used. Four pheromone traps were installed in each one of the four cardinal directions at 60 m from the release point, and another four pheromone traps were installed in each one of the four intercardinal directions at 120 m from the release point.

2.4. Data analysis

The tracking data was analyzed using SAS 9.2 (SAS, 2008) software through one-way ANOVA tests, and the Least Significant Difference (LSD) at 0.5 probability level was used to separate the means with significant difference.

3. Results

3.1. Preliminary field study

Laboratory-reared adults or partially-reared adults that had dummy transmitters attached were not able to fly under field conditions. In contrast, wild-caught adults that had dummy transmitters attached were able to fly normally. Therefore, in all subsequent tracking studies, wild-caught adults were utilized exclusively.

3.2. Tracking RPW in the absence of pheromone traps

The radio transmitter did not impede flight behavior of RPW adults. The mean mass of males and females was 1.48 and 1.46 g, respectively. The percentage of transmitter mass (0.28 g) to adult mass was 18.88% for males, and 19.19% for females (Table 1).

The first adult that took off from the platform 30 min after release and all adults left the platform independently. Before taking-off, adults walked on the platform and groomed their antennae with their front legs. Eight adults (66.67%, four males and four females) flew away from platform during the first three hours. The remaining adults either stayed on the platform or fell to the ground near the platform. However,

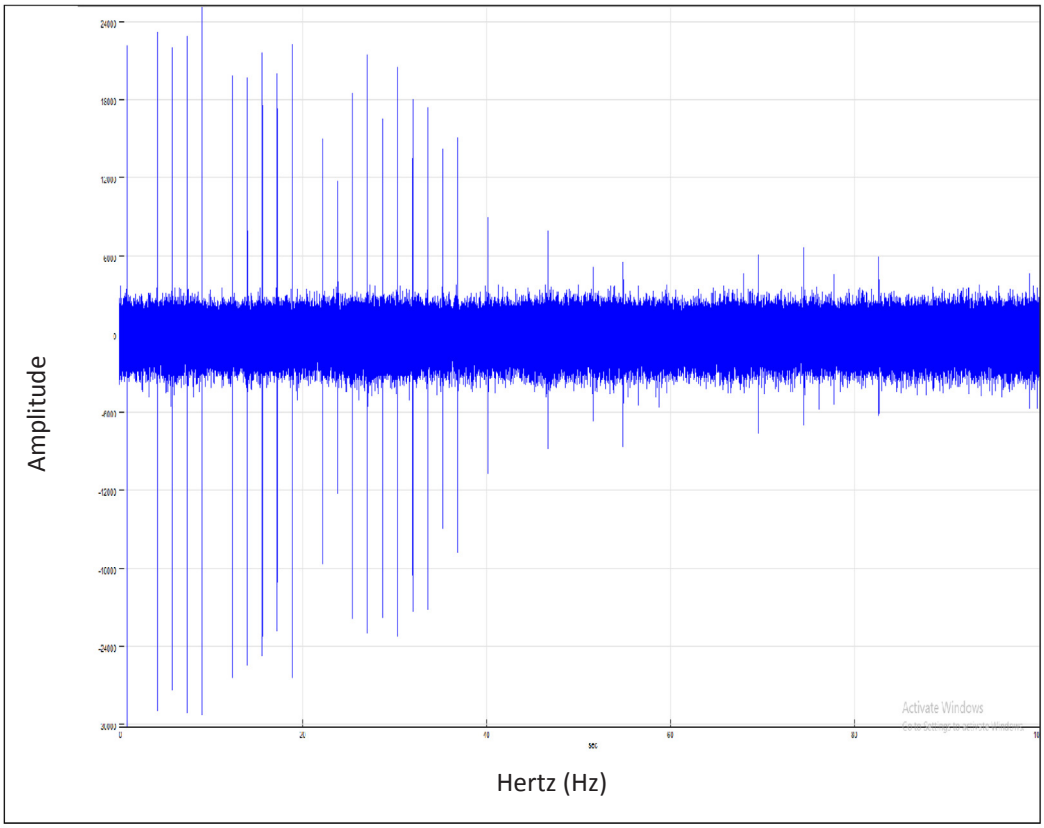

Fig. 2. The recorded signals from the transmitter form North direction.

by the second reading at 1:30 pm (six hours after release), no adults were on or near the platform. It is noted that all adults initiated only a single flight during this study. Seven out of the 12 released adults were attracted to male palm trees. Eleven tagged adults (91.7%) out of 12 flew distances of less than 50 m. The dispersal rate of females was higher than males but not significantly different. The mean distance that females and males covered was 32.47 m and 16.28 m, respectively (Table 2).

Three adults (two females and one male) took off individually to three different infested or previously infested male palm trees at distance of 10.0, 16.5 and 90 m from the release point (Fig. 4). The adult male entered previously infested tree through a hole for seven days and then moved down to the ground and was exposed to predation at day eight. The weevil's body was consumed by a predator except the portion

Fig. 3. Date palm orchard showing release point (platform A), receiver TRX 2000S (B), and tagged adult (C).

Table 1
The percent mass of transmitter to red palm weevil (RPW) mass.[1]

Type of study	Sex	RPW mass (g) ± SD	% transmitter mass[2] to RPW body mass ± SD
With absence pheromone traps	Male	1.48 ± 0.08 ab	18.88 ± 1.1 ab
	Female	1.46 ± 0.0 ab	19.19 ± 0.6 ab
With presence pheromone traps	Male	1.59 ± 0.2 a	17.76 ± 2.0 b
	Female	1.36 ± 0.1 b	20.62 ± 1.6 a

[1] Means followed with the same letter in same column are not significantly different (LSD test at level of 5%).
[2] Transmitter mass was 0.28 g.

where the transmitter was attached on (Fig. 5).

The first adult female landed on previously infested male palm tree and moved down to the ground at day four and was exposed to predation at the same day, whereas the second female entered the infested tree through a hole.

Aggregation behavior was observed with 75.0% of total adults aggregating into two groups (Table 2 and Fig. 4). In the first group, four adults (3 males and 1 female) were aggregated near a male tree at 10 m from the release point and one male climbed this tree at day four. Three adults from this group were exposed to predation at day 2, 6, and 8 days. The second aggregated group, consisting of two males and three females, was attracted to surface water from irrigation at a female palm tree at 12.6 m from the release point. RPW adults burrowed into damp soil around the tree or hid under weedy vegetation. One adult was exposed to predation at day five and another three adults at day seven.

3.3. Tracking RPW with the presence pheromone traps

The behavior of tagged adults was different in the presence of pheromone traps. The first adult took off from the platform in less than five minutes and the last one left within 20 min after release. Adults were orbiting around the platform for a short time then flew toward sites that attracted them. Six tagged adults (50%) out of 12 flew more than 50 m (Fig. 6).

These released adults also had a single flight. The habitat preferences varied among tagged adults. Three adults from 12 (25%) were attracted to pheromone traps at 60 m (two adults in different traps) and 120 m from release point. Whereas, six tagged adults were attracted to four previously infested male palm trees at a distance 9.0 m (two adults), 9.7 m (two adults), 10.0 m, and 94.5 m from the release point. One adult female was attracted to infested male palm tree at distance 213 m from release point. One adult female flew 213 m to a water basin (10 m × 4 m) and another adult female hide under discarded palm leaf bases 7.7 m from the release point (Fig. 6). No predation was observed and all adults died naturally. Aggregation behavior was decreased to 33.3% comparing with absences of pheromone traps (Table 2).

Three tagged adults (two females and one male) were attracted to pheromone traps (Fig. 6). Therefore, the efficiency of the trap was 25% (3/12 × 100). The traps also attracted 36 wild-caught adults from the surrounding palms of the orchard.

4. Discussion

Our study represents the first time RPW were successfully tracked using transmitters that were attached to the weevils in the field. Radio telemetry is usually intended for large animals due the mass and size of transmitter (Kissling et al., 2014). However, the advancement of technology has allowed researchers to use RT in tracking small animals including insects by reducing the weight and size of transmitter significantly (Hedin and Ranius, 2002; Kissling et al., 2014). The recommended ratio of the transmitter to insect body mass should not exceeding 33% (Boiteau and Colpitts, 2001). In the current study, the ratio of the transmitter to weevil body weight was approximately 19% which no doubt allowed the weevil to fly unimpeded in the palm orchards. Additionally, the selection of specific RPW adults was important in this study to achieve tracking success. The results showed that, laboratory-reared adults or partially-reared adults that were equipped with dummy transmitters were not able to fly in the orchards. In contrast, the wild-caught adults that were equipped with dummy transmitters were able to fly normally. Therefore, selection of appropriate RPW individuals was as important as choosing the tracking technique. The laboratory-reared adults apparently are highly sedentary, and are reluctant to fly. This may explain why only 11% of colony adults were able to fly in screen cages (2.5 × 2.5 × 3 m) in the study of Hamidi et al. (2017).

The two tracking experiments (with the absence and presence pheromone traps) indicated that RPW adults apparently only fly once. Single flights may be adaptive to RPW by reducing the risk of exposure during flying in orchards. In nature, adults are rarely observed flying in infested palm orchards. Additional studies are required to confirm that RPW only have a single dispersal flight. It was observed that adults remained at the release point platforms for a period of time before flying. This may be explained by adults detecting palm allelochemicals resulting in directional flights toward the source. Curculionids are attracted by allelochemicals released by the fermenting tissues of wounded or drying host-plants (Zagatti et al., 1997).

Our study showed that tagged adults could fly a distance of up to 213 m. Ávalos et al. (2014), however, reported that the RPW fly up to 500 m. This is because they used untagged adults and may be that the environmental conditions were more conducive for the adults to fly. The short flying distances by the RPW adults may be beneficial allowing for aggregating at infested palm trees. Clumped or aggregated patterns of the RPW adults have been reported (Faleiro et al., 2002). Additionally, infested palm trees were observed to occur in clusters at Al-Hassa, Kingdom of Saudi Arabia (Anon., 1998). Prompt control efforts should be focused on sources of infestation of the RPW in orchards to prevent adult dispersal.

The tracking study provided new information on movement and habitat preferences of the RPW adults. RPW adults were attracted to infested trees, male palm trees, and surface water of drip irrigation systems, water basins, pheromone traps, and cuttings of palm trees such

Table 2
Characterization of red palm weevil tracking in absence and the presence pheromone traps.

Features	Sex	With absence pheromone traps (mean ± SD), range	With presence pheromone traps (mean ± SD), range
Distance crossed in meter	Male	16.28 ± 4.96 a, (11.4–26.2)	42.40 ± 48.23 a, (7.7–124.5)
	Female	32.47 ± 25. 98 a, (17.1–90.0)	95.80 ± 85.43 a, (9.7–213)
	Mean total	24.38 ± 20.38 a, (11.4–90.0)	69.10 ± 74.33 a, (7.7–213)
% Aggregation		75.00	33.30
% Predation		66.60	0.00
Temperature °C		27.30 ± 2.05, (24.83–31.00)	34.40 ± 1.40, (32.18–35.63)
% Relative Humidity		25.40 ± 6.30, (17–36.67)	26.00 ± 6.40, (20–36.75)
Wind speed m/sec.		2.60 ± 0.80, (1.46–3.83)	2.30 ± 0.40, (1.78–2.77)

Means followed with the same letter in same row are not significantly different (LSD test at level of 5%).

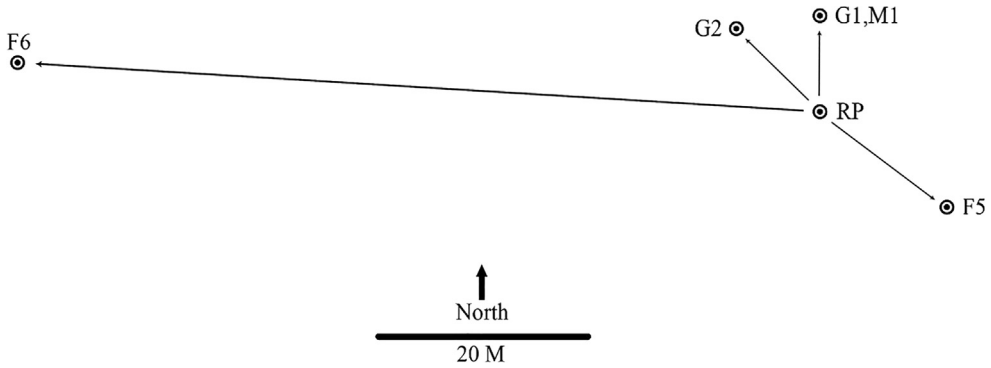

Fig. 4. Movement patterns of 12 red palm weevils with absence pheromone traps. Where: RP = release point; G1 = first aggregated group including male no. 4, 5, 6 and female no. 4); G2 = second aggregated group including male no. 2, 3 and female no. 1, 2, 3; F5 = female no. 5, F6 = female no. 6, M1 = male no. 1

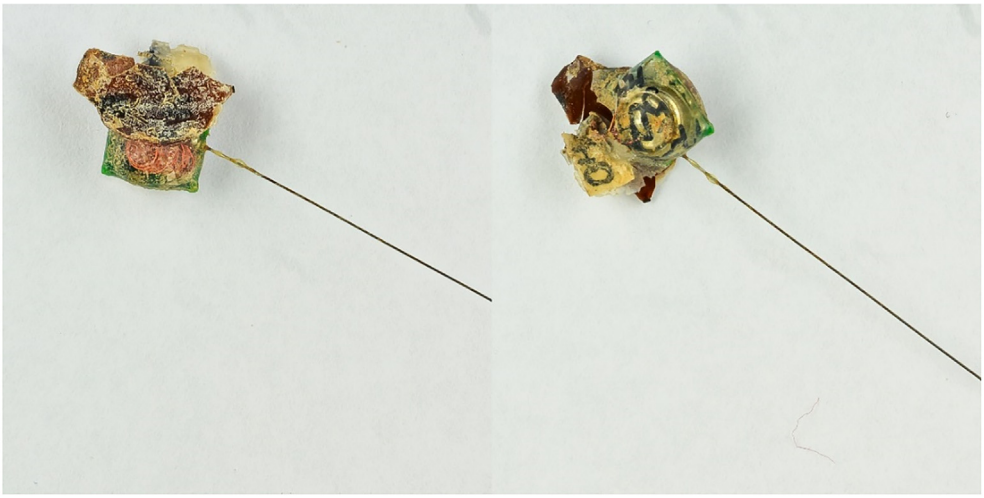

Fig. 5. The transmitter and the remaining body of the weevil after predation (Left = ventral view, Right = dorsal view).

as leaf bases. RPW adults being attracted to water is well documented (Aldryhim and Khalil, 2003). The proper maintenance of irrigation systems avoiding water leakage may decrease survivability of RPW adults. Tagged adults were attracted to male date palm trees in the absence and presence of pheromone traps. Ali-Bob (2019) found that male palm trees were more prone to RPW infestations. Uribarrena-Bollain (2013) found in Valencia that 50% of infested tree, *Phoenix dactylifera*, were males and 16.7% were females, and 33.3% undetermined.

Tagged females of RPW dispersed further than tagged males both in the absence or presence of pheromone traps. Several factors may affect the flight distance of both female and male (Ávalos et al., 2014). Beaudoin-Ollivier et al. (2003) found that tagged females of the Melanesian rhinoceros beetle *Scapanes australis* (Boisduval) dispersed further than males. Also similar results were reported with the great Capricorn beetle *Cerambyx cerdo* L. (Drag and Cizek, 2018).

The presence of pheromone traps modified the behavior of the RPW adults as compared with no pheromone traps. The RPW adults flew from the release point more quickly; aggregation rates were lower; adults traveled further; and no predation was observed in the presence of pheromone traps. This is the first report of the effect of synthetic aggregation pheromone on the behavior of the RPW adults. Previous studies focused on using traps baited with synthetic aggregation pheromone lure as part of integrated pest management (Abraham et al., 2000; Abdel-Azim et al., 2017). Sweeney et al. (2017) found that use of an aggregation pheromone in baited traps disrupted mating for the brown spruce beetle *Tetropium fuscum* (F.). Further research is suggested to ascertain the effects of using synthetic aggregation pheromone in traps on behavior of RPW adults and subsequently on the infestation rates of date palm trees.

5. Conclusion

This study is the first successful trial for tracking red palm weevil using a radio telemetry technique in a date palm orchard. Useful and new information was provided on adult behavior and habitat preferences of RPW which may be incorporated into pest management programs for the RPW. Application of pheromone traps modified the RPW adult behavior. More dispersion and less aggregation rates occurred in the presence of pheromone traps.

Adults were obviously attracted to male date palm trees, which require more inspection to detect the infestation as a preventive measure. Male trees could be used as plant traps for red palm weevil. Further investigations are suggested here for using male trees as a tool of integrated pest management.

Author statement

This research is part of the doctoral dissertation of the first author under the supervision of the second and third authors.

Declaration of Competing Interest

The authors declared that there is no conflict of interest.

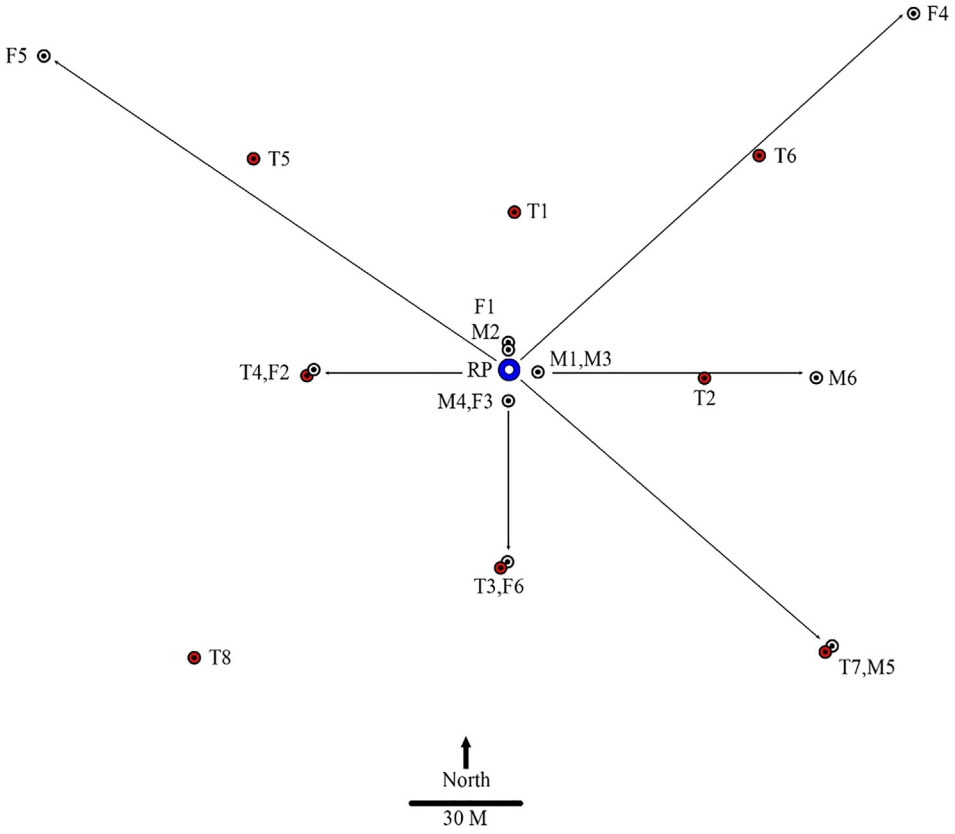

Fig. 6. Movement patterns of 12 red palm weevils with presence pheromone traps. Where: T1-T4 = pheromone traps at 60 m from the release point; T5-T8 = pheromone traps at 120 m from release point; F1-F6 = tagged females and M1-M6 = tagged males. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.compag.2020.105252.

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