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An Assessment of the Efficacy of Pheromone Traps in Managing the Red Palm Weevil

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ABSTRACT

This experiment was performed in date palm farms to assess the effectiveness of a newly designed pheromone trap (i.e., funnel trap) in capturing red palm weevil (RPW) adults and to compare it to traditional traps. The number of captured RPWs varied by month, with a total of 3931 adults captured during the experiment. Analysis of variance demonstrated significant differences in the number of captures between the three traps. The funnel traps captured 1627 RPW adults in total, while the buried and burlap bucket traps captured 1079 and 1225 weevils, respectively. The mean (± SE) number of captures/trap/weeks was 2.62 ± 0.11 in funnel traps, which was significantly higher than that of buried bucket traps (1.73 ± 0.06) and burlap bucket traps (1.97 ± 0.07). Both sexes were attracted to traps; however, the number of female weevils captured was significantly higher than that of males with a sex ratio (female/male) of 1.58 ± 0.03. According to the findings, the pheromone-food-bait funnel trap is a promising solution for reducing RPW populations and thus protecting date palm trees from infestations.

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1. INTRODUCTION

The date palm (*Phoenix dactylifera L.*) is recognized as one of the most valuable commercial fruit species in the United Arab Emirates (UAE), as well as its social importance and heritage prestige (Chao and Krueger, 2007). Coleopteran weevils attack a diverse range of palm species across the globe (Kassem, *et al*., 2020). The red palm weevil (RPW) *Rhynchophorus ferrugineus Olivier* (Coleoptera: Dryophthoridae) is one of the biggest threats facing palm agriculture today. This invasive species is originated from Southeast Asia and Melanesia. By the mid-1980s, the pest had spread to the Middle East, and then it moved into northern Africa and southern Europe, eventually reaching North America in 2009 (Faleiro, 2006; Rugman-Jones, *et al*., 2013). Ecological niche models predict that this pest can expand its range into novel climatic environments (Witt, *et al*., 2020). In Morocco, “Bayoud”, a vascular wilt disease, incited by the soilborne fungal pathogen *Fusarium oxysporum f. sp. albedinis (FOA)*, was treated by *Asteriscus graveolens (Forssk.)* oil rich by 6 -Oxocyclo-nerolidol, cis - 8 - acetoxy chrysanthenyl acetate, cis-chrysantenylacetate, 6-hydroxy cyclonerol idol, cadinol and oxobisabolene (0.2–5.5 wt%). Mycelial growth and spore germination of FOA were found to be strongly inhibited by the oil when tested using agar dilution assay (Chibane, *et al*., 2020).

Rhynchophorus ferrugineus has significant socio-economic impact on the date palm production sector and livelihoods of farmers in affected areas of North Africa and the Middle East (Faleiro, 2006). This insect pest attacks over 40 palm species (Antony, *et al*., 2021) by using their strong jaws to burrow from the axils of the leaves to the crown, where they feed voraciously. These trees are killed once infested, resulting in enormous losses of sustainable income and food supplies for thousands (Dembilio, *et al*., 2010).

Early detection of *R. ferrugineus* is generally difficult since the larva feeds inside the date palm trees and the related damage is generally visible only after long-term infestation (Dembilio and Jacas, 2011). Furthermore, this feeding behavior provides significant protection for the larvae against chemical insecticides (Shi, *et al*., 2014). As a result, particular emphasis is placed on the implementation of an integrated pest management (IPM) approach by using, in particular, pheromone mass trapping and biocontrol methods.

There are many preventive and curative strategies for controlling RPW populations: early detection, use of pesticides, removal of severely-infested palms, mechanical sanitation, and utilization of pheromone-food-bait traps (Al-Dosary, *et al*., 2016; Kassem, et al., 2020). Due to the poor effectiveness of the control measures mentioned above, this insect still causes substantial losses to the economy and landscape (Faleiro, *et al*., 2019).

Since chemical applications raise serious concerns about environmental pollution and have an impact on human health, interest has now turned to eco-friendly biological control and to develop an efficient mass trapping system. Indeed, RPW monitoring and mass trapping using pheromone-food-bait traps is commonly studied (Faleiro and Chellapan, 1999; El-Sayed, *et al*., 2006; Vacas *et al*., 2013; Oehlschlager, 2016). In order to maintain trapping efficiency, it is important to follow the best trapping protocols regarding pheromone lure, food-bait, trap density, placement and servicing (Navarro-Llopis *et al*., 2018; Vacas *et al*., 2014).

Hallett, *et al*. (1999) demonstrated that the synthetic aggregation pheromone see **Figure 1** is more attractive to *R. ferrugineus* when coupled with kairomones or volatiles released from the host plant.

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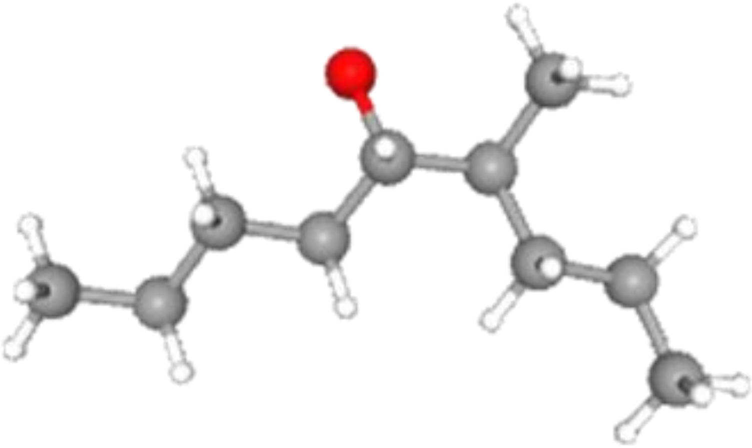

Figure 1. Spatial chemical structure of ferrugineol (4-Methyl-5-Nonanol) as an aggregation pheromone for Rhynchophorus ferrugineus (Soroker, *et al*., 2005)

Furthermore, pheromone traps with dates mixed in water attract high numbers of RPW adults than other food baits (Faleiro and Satarkar, 2005). Insecticides can also be integrated into the pheromone traps to prevent weevils escaping. Adding water to traps baited with palm tissues is crucial, as this attracts significantly more RPW adults than the dry traps (Vacas, *et al*., 2013). Ethanol and Ethyl acetate, as fermenting compounds, may also enhance the attractiveness of aggregation pheromones and eventually substitute natural kairomones in *R. ferrugineus* trapping systems (Oehlschlager, 2016; Vacas, *et al*., 2017).

Other variables such as trap design, color, height and weather conditions all have an effect on the ability of pheromone-food-bait traps to catch higher numbers of RPW adults (Abuaglala and Al-Deeb, 2012; Hallett, *et al*., 1999; Navarro-Llopis *et al*., 2018). Standard bucket traps are utilized in combination with pheromone traps to improve their effectiveness or to add new functions to the trap (Fanini, *et al*., 2014; Guarino *et al*., 2011). On the other hand, Vacas *et al*., (2013) reported that dome shaped traps captured more weevils than bucket traps. In Saudi Arabia, experiments with the service-less pheromone trapping options 'attract and kill' traps as well as the dry trap that operates on 'electromagnetic radio waves' have been shown to be promising (El-Shafie, *et al*., 2011).

A trap designed to capture walking or flying weevils is important to successfully manage RPW populations (Cork, *et al*., 2003). This study was undertaken to assess the effectiveness of a newly designed pheromone trap in capturing *R. ferrugineus* adults, to compare it with conventional bucket traps already used in UAE, and to determine the importance of pheromone-food-bait traps in control management programs.

2. METHODS

2.1. Study sites

The experiment was conducted in three sites on northern, central and eastern region in UAE from April 29 to December 08, 2014 (Site 1: 25°34'33.77"N, 55°57'19.79"E; Site 2: 25°8'9.36"N, 55°44'30.05"E; Site 3: 25°20'40.37"N, 56°19'30.45"E) see **Figure 2**. Three date palm farms with an area of more

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than 12 ha, and with moderate to severe infestation and between 10 to 15 years of age were considered for this experiment. Date palms under the age of 20 are typically the most affected, with most of the infestation being limited to the trunk at a height of one meter above ground (Kassem, *et al*., 2020).

2.2. Treatments and experimental design

Three trap types were tested during this study see **Figure 3**. In UAE, the buried bucket trap (Trap 'A') has been commonly utilized for monitoring and mass trapping of *R. ferrugineus* adults. This traditional trap consists of a white plastic bucket with a lid (10 L, 30 cm height), four equidistant 9 cm2 lateral windows (4 cm below the upper rim of the bucket), and four identical windows on the lid. The trap is placed buried in the soil till the holes are level to the ground to facilitate the entry of weevils.

The bucket trap with burlap covering (Trap 'B') has same characteristics like the buried bucket trap but the bucket's outer surface was roughened with burlap glued to the exterior to enable RPW adults climb up the trap quickly and then reach the inside via the windows, instead of sliding off the smooth surface of the bucket. The trap was placed on the ground and part of it was covered with sand in order to safely fix it in place and to prevent wind or any other external factors from overturning the trap.

The newly designed funnel bottle trap with a single-entry point on lid (Trap 'C') was made by cutting off the neck of the bottle (15 L and 40 cm height) and the entire tapering part of the top. The cap of the bottle is removed. The tapering part is mounted upside down on top of the rest of the bottle, thus forming a funnel efficiently. The funnel is then attached to the bottle with black paper clips (25 mm). The bottle's outer surface was wrapped with burlap glued to the exterior to enable RPW adults climb up the trap quickly and enter inside. The trap was placed on the ground and part of it was covered with sand in order to safely fix it in place and to prevent wind or any other external factors from overturning the trap.

All traps were loaded with commercially available aggregation pheromone (FerrolureTM 700 mg, ChemTica International S.A., San Jose, Costa Rica), 350 g of dates as a fermenting fruit bait, 150 ml of ethyl acetate, and 4 L of water. The pheromone and ethyl acetate dispensers were hung by a metal wire from the middle of the trap cover. Dates that had previously been immersed in water for 24 h prior were then squeezed to drain the water before being used in traps. As needed, water was replenished to retain adequate moisture and to drown the weevils in the traps. Pheromone lure and dates were changed on monthly basis to maintain trapping efficacy.

The experiment was conducted as a randomized complete block design with three treatments (pheromone-food-bait trap 'A', 'B' and 'C') and eight replicates. Each trap was given a serial number and locations were numbered on each site from 1 to 24. All traps were placed 5 m from the border of each farm, and the distance between them was approximately 100 m. A perforated ladle was utilized to collect the captured weevils, and the trap was shaken to ovoid fungi or mold from growing. The counts of RPW weevils were taken every week. After the count, each trap was rotated so that each trap appeared at each place for one week period to prevent location effects on collected weevils (Faleiro, *et al*., 2002).

2.3. Statistical analysis

The data on weekly numbers of R. ferrugineus adult captures per trap were found to be non-normally distributed and thus, the Kruskal-Wallis (K-W) one-way nonparametric test was utilized to verify the effect of trap type on mean number of captured weevils per trap. If this test exposed a significant effect ($\alpha = 0.05$), differences among the traps were confirmed by using the Dunn's test. SPSS Statistics version 16.0 (SPSS Inc., Chicago, IL) was used to analyze the data.

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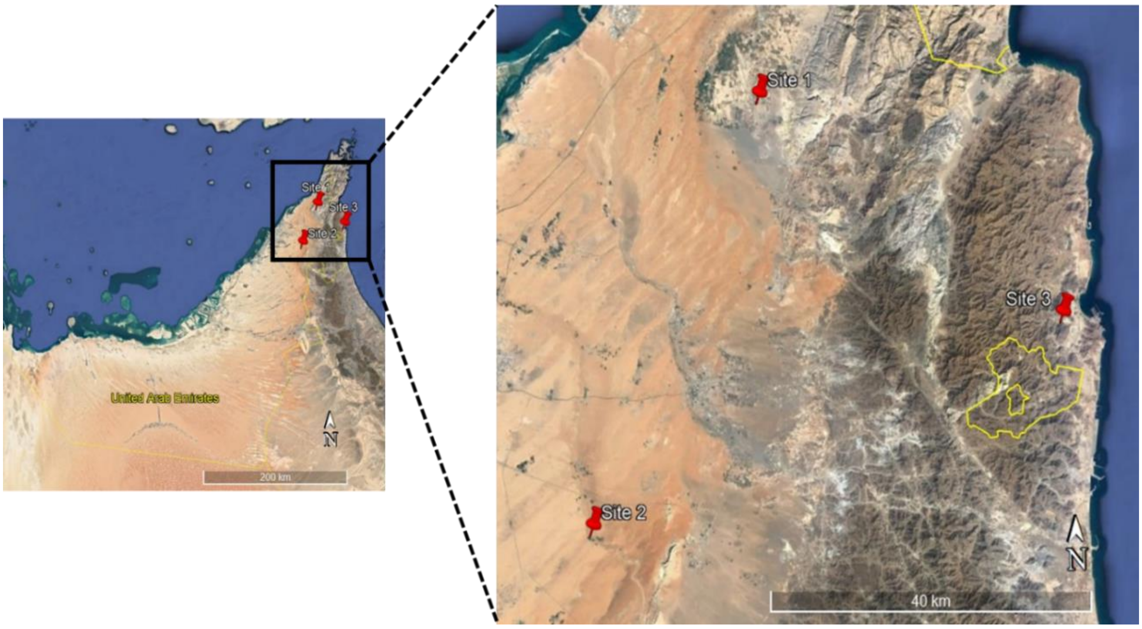

Figure 2. Locations of study sites for *Rhynchophorous ferrugineus* trapping experiments. The inset map indicates the location of the main map in the United Arab Emirates.

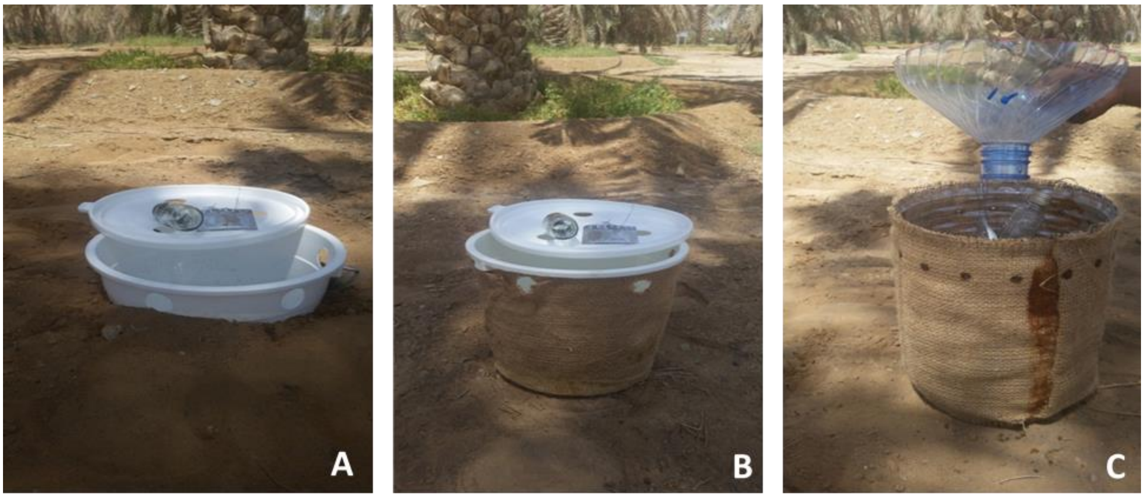

Figure 3. The three types of pheromone-food-bait traps used in the experiments: 'A': buried bucket trap; 'B': bucket trap with burlap; and 'C': funnel bottle trap with single entry point on lid

3. RESULTS AND DISCUSSION

3.1. Activity of RPW in date palm farms

From April to December 2014, the average number of red palm weevils in the first site (northern region) reached about 2.16 ± 0.15 weevils per trap, compared with 2.05 ± 0.06 and 2.13 ± 0.06 adults per trap in the second (central region) and third site (eastern region), respectively (K–W test; $\chi 2 = 24.89$, df = 2, $p < 0.0001$) see **Table 1**. *Rhynchophorus ferrugineus* was present during the experiment period, but the numbers of the captured RPWs varied across the months.

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Figure 4 demonstrates the fluctuation of *R. ferrugineus* populations. This fluctuation can also be noted on a weekly basis. There were two population peaks during the experimental period: the first peak being in May and the second in October, with monthly mean numbers of adult captures/trap of 2.76 and 2.60 adults, respectively.

Rhynchophorus ferrugineus seasonal fluctuations can be monitored by analyzing the numbers of weevils captured in pheromone traps. Our results indicated high capture rates during May and October in 2014 which support those reported by Al-Saoud (2018). They demonstrated that RPW captures in UAE reflected similar trends, with a major peak during the spring and a smaller one in the fall. Also, two activity peaks of R. ferrugineus were noticed during April and November in Egypt (El-Sebay, 2003). El-Garhy (1996) reported high capture rates of this insect during the period of April - June, which slowed down during the winter season. Likewise, in Saudi Arabia, Abraham, *et al*., (1999) have shown that the high capture rates of weevils were during May and September in 1997.

Furthermore, RPW has high activity during spring rather than autumn (Vidyasagar, *et al*., 2000). Eggs laid in autumn are typically caught in the winter, resulting in fewer infestations compared to oviposition occurring during the first peak between March and May (Faleiro, 2006). However, RPW reproduction occurs throughout the year, and as a result damage from this pest is high and control by chemical insecticides is difficult to attain, since their application must cease during the pollination period (mid-February to the end of March), and during the crop maturing and harvesting season (June - October). For adequate control of this pest, pheromone trapping must be combined with other IPM techniques, such as regular inspection of date plantations, removal of heavily infested trees, and phytosanitary measures (El-Shafie and Faleiro, 2017).

Table 1. *Rhynchophorus ferrugineus* response to different pheromone-food-bait traps in date palm farms, United Arab Emirates from April 29 to December 08, 2014

	Number of adult captures/trap	Mean (± SE) number of adult captures/trap/week	Ratio (Female/Male)
Site 1	**974**	**2.16 ± 0.15[a]**	**1.26 ± 0.10[a]**
Trap ‘A’	221	1.47 ± 0.17	1.18 ± 0.19
Trap ‘B’	284	1.89 ± 0.23	1.40 ± 0.22
Trap ‘C’	469	3.13 ± 0.34	1.21 ± 0.09
Site 2	**1475**	**2.05 ± 0.06[b]**	**1.71 ± 0.04[b]**
Trap ‘A’	446	1.72 ± 0.09	1.65 ± 0.08
Trap ‘B’	460	2.00 ± 0.09	1.77 ± 0.07
Trap ‘C’	576	2.43 ± 0.12	1.70 ± 0.06
Site 3	**1482**	**2.13 ± 0.06[b]**	**1.58 ± 0.04[b]**
Trap ‘A’	412	1.92 ± 0.08	1.60 ± 0.05
Trap ‘B’	481	1.98 ± 0.09	1.57 ± 0.06
Trap ‘C’	582	2.48 ± 0.13	1.57 ± 0.06
Total	**3931**	**2.11 ± 0.05**	**1.58 ± 0.03**

Different letters above the columns denote statistically significant differences at $P < 0.05$ (Dunn’s test). Site 1: Al-Hamraniah, northern region; site 2: Qatah, central region; and site 3: Khorfakkan, eastern region. ‘A’: buried bucket trap; ‘B’: bucket trap with burlap; and ‘C’: funnel bottle trap with single entry point on lid. SE: standard error of the mean.

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3.2. RPW sex ratio

Sex differences in trap captures have been noted. Both sexes were attracted to traps; however, the number of female weevils captured was significantly higher than that of males with a sex ratio (female/male) of 1.58 ± 0.03 (based on a total of 1866 specimens). The female/male ratio in the first site was 1.26 ± 0.10, compared with 1.71 ± 0.04 and 1.58 ± 0.04 in the second and third site, respectively (K–W test; $\chi 2$ = 74.19, df = 2, p <0.0001) see **Table 1**. Trap design did not influence this ratio (K–W test; $\chi 2$ = 2.62, df = 2, p = 0.270) see **Table 2**.

Results showed that *R. ferrugineus* captures were female dominated during the study period see **Figure 4**. The sex ratio of the weevil population is assumed to be 1:1. However, in various pheromone trapping experiments, the captures in traps are dominated by females with a ratio of about 1:2 (males:females) (El-Garhy, 1996; Vacas, *et al*., 2013; Aldryhim and Ayedh, 2015). In this study, the overall average of sex ratio (females/males) was 1.58 ± 0.03 which is slightly lower ratio than those found in the literature. The number of female captures per trap is almost higher than that of males (Faleiro, 2006), which could be attributable to the fact that females disperse more rather than males looking for suitable food sources for their offspring (Soroker, *et al*., 2005). In addition, the male-released aggregation pheromone might attract more female weevils than males. RPW females lay about 250-350 eggs within the palm tissue (Kassem, *et al*., 2020), and the offspring will be spread from an infested tree to infest others in few months. A significant number of date palms can be destroyed by *R. ferrugineus* in a short period of time due to the insects' fecundity and dispersal capacity. High female captures in mass trapping programs help to reduce the RPW outbreaks (Oehlschlager, 2007).

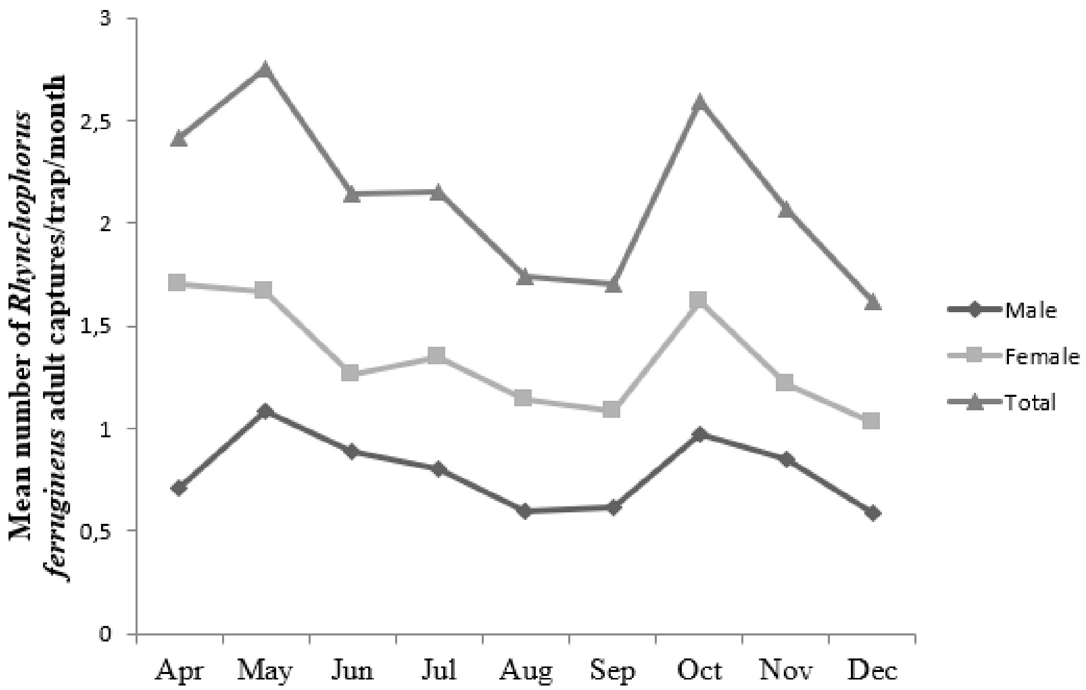

Figure 4. Average monthly catch of *Rhynchophorous ferrugineus* adults per pheromone-food-bait trap in date palm farms located at the northern, central and eastern regions of the United Arab Emirates from April 29 to December 08, 2014

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Table 2. Trapping efficacy of different pheromone-food-bait traps in capturing red palm weevil adults in the United Arab Emirates from April 29 to December 8, 2014.

	Number of adult captures/trap	Mean (± SE) number of adult captures/trap/week	Ratio (Female/Male)
Trap 'A'	**1079**	**1.73 ± 0.06[a]**	**1.55 ± 0.05[a]**
Site 1	221	1.47 ± 0.17	1.18 ± 0.19
Site 2	446	1.92 ± 0.08	1.60 ± 0.08
Site 3	412	1.72 ± 0.09	1.65 ± 0.06
Trap 'B'	**1225**	**1.97 ± 0.07[a]**	**1.56 ± 0.04[a]**
Site 1	284	1.89 ± 0.23	1.40± 0.22
Site 2	460	1.98 ± 0.09	1.77 ± 0.07
Site 3	481	2.00 ± 0.09	1.57 ± 0.06
Trap 'C'	**1627**	**2.62 ± 0.11[b]**	**1.63 ± 0.05[a]**
Site 1	469	3.13 ± 0.34	1.21 ± 0.09
Site 2	576	2.48 ± 0.13	1.70 ± 0.06
Site 3	582	2.43 ± 0.12	1.75 ± 0.06
Total	**3931**	**2.11 ± 0.05**	**1.58 ± 0.03**

Different letters above the columns denote statistically significant differences at P < 0.05 (Dunn's test). 'A': buried bucket trap; 'B': bucket trap with burlap; and 'C': funnel bottle trap with single entry point on lid. Site 1: Al-Hamraniah, northern region; site 2: Qatah, central region; and site 3: Khorfakkan, eastern region. SE: standard error of the mean.

3.3. Impact of trap designs on number of captured weevils

During the field experiment, a total of 3931 *R. ferrugineus* adults (2.11 ± 0.05 individuals per trap per week) were captured see **Table 1**. The trap design had a significant effect on weevil captures at sampling sites (K–W test; northern: $\chi2 = 13.70$; df = 2; $p < 0.001$; central: $\chi2 = 18.48$; df = 2; $p < 0.0001$; and eastern: $\chi2 = 8.38$; df = 2; $p = 0.015$). According to the results of Dunn's test, significantly more weevils were captured in pheromone-food-bait funnel traps than in buried or burlap bucket traps see **Table 1**. Collectively, the comparison between the means (± SE) for the total numbers of adult captures per trap in all sites by using each of the different trap designs see **Table 2** confirms the aforementioned findings (K-W test; $\chi2 = 36.32$, df = 2, $p <0.0001$). The funnel traps captured a total of 1627 RPWs, while the buried and burlap bucket traps captured 1079 and 1225 weevils, respectively. The mean weekly trap catch of *R. ferrugineus* adults was 2.62 ± 0.11 in funnel traps, significantly higher than those captured by buried bucket traps (1.73 ± 0.06) and burlap bucket traps (1.97 ± 0.07) see Table 2. The highest trap catch was on October 02, 2014, where 25 adults were captured per funnel trap, 20 adults per buried bucket trap, and 9 adults per burlap bucket trap.

Palm weevils are found in relatively small numbers in most date palm farms and have a longlife span (Abdel-Azim, *et al*., 2019). These features make it possible for intensive trapping to be an effective control strategy as the trapping of low numbers will have an impact on subsequent populations and a considerable percentage of a weevil population can be caught over a long time period, they are vulnerable to traps baited with the synthetic pheromone and food materials. Since RPW is considered as a strong flyer, pheromone traps can be widely spaced (Hoddle, et al., 2015) and trapping is more effective than spraying to control *R. ferrugineus* populations (Oehlschlager, 2007). Consequently, the traps of greatest

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efficacy are those that facilitate the entry of weevils; Traps should then be constructed taking into account the RPW behavior.

The current study on trapping RPW adults in date palm farms in UAE reveal that capture rates were significantly affected by the trap design. Our results demonstrate that the funnel traps are more effective in trapping R. *ferrugineus* weevils than the traditional ones (bucket traps). Collectively, the percentages of captured weevils per trap in the three sites were 41, 31, and 27 % for funnel traps, burlap bucket traps, and buried traps, respectively. With regards to the trap design, the four-window bucket trap was commonly used to trap RPW. In contrast to bucket traps, dome-shaped traps catch more weevils (Vacas, *et al*., 2013). However, even though the dome-shaped trap is successful, the required time to service this trap can be longer. Bucket traps set on the ground have been recorded to be the most efficient since they make easier the entry of *R. ferrugineus* adults (Hallett, *et al*., 1993; Faleiro, 2006). Moreover, the bucket traps captured a higher number of RPW adults than pyramidal traps (Al-Saroj, *et al*., 2017). The inverted bucket trap was less efficient as compared to the straight bucket trap, possibly due to the fact that the moisture which is essential to catch RPWs could be lost quickly. In contrast, straight buckets are easy to service and retain moisture for a long period. Even more, straight bucket traps with a roughened outer surface were the most successful. In Saudi Arabia, the upright bucket trap surrounded by a mat is the preferred trap for *R. ferrugineus* (Hoddle, *et al*., 2013), and the bucket trap with a molded rough surface is usually utilized in UAE.

As *R. ferrugineus* flies, lands and then walks into the trap, a roughened outer surface of the trap is required to allow the weevil to climb comfortably into the trap. Notoriously, most trap types are unable to catch all the weevils that are drawn to their vicinage, due to the weevil escape or the difficulty to reach the inside of the trap. Escape ratios ranging from 2 to 43 % were also noticed when comparing the efficacy of different trap types to capture other coleopterans such as the sweet potato weevil, *Cylas formicarius* (Coleoptera: Brentidae), and the West Indian sugarcane weevil, *Metamasius hemipterus sericeus* (Coleoptera: Dryophthoridae) (Giblin-Davis, *et al*., 1996; Jansson, *et al*., 1992). As demonstrated in the present study, funnel traps captured significantly more RPW adults than the standard bucket model. It was expected that once *R. ferrugineus* weevils enter inside the funnel trap, escape of the captured adults is prohibited because of the existence of a single-entry point which is in the middle. Furthermore, this trap's outer surface was wrapped with burlap glued to the exterior to enable RPW adults climb up the trap quickly and enter inside.

4. CONCLUSION

Mass-trapping using pheromone-food-bait traps is very promising to monitor *R. ferrugineus* and reduce its populations in date palm farms. The present work provides a new hand-made funnel trap design, which shows good efficacy in capturing RPW adults. Further work needs to be done on optimizing the use of this trap under field conditions, such as the position and distribution pattern, and the duration of the trapping period. Additional considerations that lead to difficulties in managing RPW include high dispersal ability and fecundity of the pest, high host density in certain regions, and poor capacity to detect infested palm trees before damage occurs. Each of these challenges should be addressed in subsequent research.

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6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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