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The Dynamic Fluctuation of Red Palm Weevil *Rhynchophorus Ferrugineus* (Olivier) in Makkah Al-Mukarramah city

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The red palm weevil(RPW),*Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Dryophthoridae) is one of the most threatening pests of date palm trees in Kingdom of Saudi Arabia (KSA). Which considered as category Iinsect pest in the Gulf region and the Middle East, according toFood and Agriculture Organization (FAO). Therefore, this research was planned to study the dynamic fluctuation of RPW, its relationship to some environmental factors (temperature & relative humidity) and to determine sexual ratio in Makkah city during 2019. In addition to clarifying color preference by using food bait pheromone traps (FBPTs). The results revealedthe presence of RPW throughout the year, with significant differences in numerical densities according to different collection times. The study also recorded the highest population density during April & March, and it was the highest significantly compared to that were collected during July, October, August and September. The study also recorded two peaks of RPW activity throughout the year. A major summit in April and a smaller summit in December. Statistical analysis results showed that the RPW has significant activity at spring compared to the other seasons, while the least active for RPW was at autumn.The results also showed a negative significant correlation between the mean population density of RPW and temperature; and a positive non-significant correlation between seasonal abundance and relative humidity, with significant differences between the mean of male and female with ratio(1:3), respectively. Black traps were more effective and significantly in attracting RPW than other tested colors.

Keywords: Control; Makkah Al Mukarramah; Pheromone traps ;Relative humidity; *Rhynchophorus Ferrugineus*; and Temperature.

The palm trees have economic importance at the global level as they are one of main food sources in many countries, as indicators confirm that palm tree cultivation is constantly growing. The number of palm trees in the world is 120 million date palms, 70% of them present in the Arab world, with a production rate of 67% and 28% of it in the Gulf countries, and that is from the global production of dates, which is estimated at about 6.7 million tons[1;2;3 & 4]

Kingdom of Saudi Arabia is second largest producer of dates in the world with an

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estimated rate of 14.96% of the global production of dates[5 & 6], as there it has more than 400 cultivars of palm varieties in the world and 25of them are important[7;8 & 9].The number of palm trees planted in the Kingdom of Saudi Arabia is estimated at about (28570884) palm trees, and the Makkah region contains about (1237568) palm trees[10].

On the other hand, palm trees are affected by many insect and non-insects pests, but the RPW*Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Dryophthoridae) is one of the most dangerous invasive pests that threaten date palm trees and cause them a lot of damage and economic losses[11]. The annual losses in the Middle Eastern countries are estimated by millions of dollars, with a loss of 30% of the total date production[12].

The first infection with RPW in the KSA was recorded in of Hofuf city in 1987 AD[13]. Although the first recording by red palm weevil infestation in the world was on coconut palms, it was able to expand the range of its host from palm trees to (40) species, the most important of which are date palms[14;15;16 &17.] According to FAO It is classified as category-1 pest of date palm in the Middle-East[5;9;18;19 & 20].

Red palm weevil larvae are the most destructive stage to the palm, as they feed on the internal tissues of palm and complete their growth and development internally[20 & 21]. This cryptic habitat of RPW affects the early detection process of infestation with it, and thus makes controlling it a difficult task, in addition this behavior provides protection from harsh climatic conditions, which enhances its presence in a wide and varied environmental range, and this is the biggest challenge facing RPW control[22;23 & 24] considered that the use of pheromone traps as part of an Integrated Management Strategy (IPM) to control RPW is an environmentally friendly tool, easy to handle, long lasting and does not make resistances .pheromone traps have been widely used in many countries of the world, including Saudi Arabia, as part of the integrated RPW control strategies[25 & 26].

In view of the scarcity of recent and integrated environmental studies on the RPW in the Makkah Al Mukarramah region and based on Saudi Arabia's vision 2030 in diversification of the Kingdom's production base, achieving food security, by increasing the contribution of the agricultural sector to the local product, advancing economic development, and reducing the infestation of RPW from currently estimated 10% to 1%,[27]. The aim of this research is to study the dynamic fluctuation and determine the seasonal variations of abundance of adults RPW and effect of temperature and relative humidity on weevils' activity during the year in Makkah city, and the effectiveness color of pheromone traps on monitoring RPW populations.

MATERIALS AND METHODS

Ecological study area

Environmental studies were carried

Fig. 1. Study site of dynamic fluctuation for RPW. ainted with the tested colors and each color had four replicates.

out in the farms that are located in Makkah Al-Mukarramah Governorate in the western part of KSA Fig.(1) from January through December (2019), with the agreement of farm owners the control operations which were provide by the Ministry of Environment, Water and Agriculture to the farmers were stopped.The sites were selected on the basis of the large number of farms that were infested with theRPW, to monitoring the dynamic fluctuation of the red palm weevil during the four seasons (spring, summer, autumn and winter) and determining the relationship between the numerical density of the red palm weevil and the climatic conditions (temperature and relative humidity), by using food bait pheromone traps (FBPTs).A total of 40 traps were randomlyinstalled according to the method describe by [28], the distance between each trap not less than 12 meters . The traps were inspected once every fortnightlyin order to collect RPWand replace freshfood baits and water.

Fig. 2. The adult male and female of RPW

Sex ratio

The sex of adult RPW was distinguished, depending on the morphological characteristics, where the males contain bristles on the rostrum while it was absent in the females (Fig. 2).

Color preference experiment

Three colors were tested (black, red and white with the natural color of burlap), where the traps were painted with the tested colors and each color had four replicates.

Statistical analysis

The completely randomized design was used, and the results were analysis using the general linear models procedure method. The statistical software, 2001 (SAS) program was used to analyze the field results and compare the averages using the least significant difference (LSD) test at the level of significance. (0.05), and the Pearson Correlation Coefficient was used to determine the relationship between the RPW population density and the climatic conditions (temperature, relative humidity).

RESULTS

The results showed the presence of RPW in traps throughout the year, with significant differences in numerical densities according to

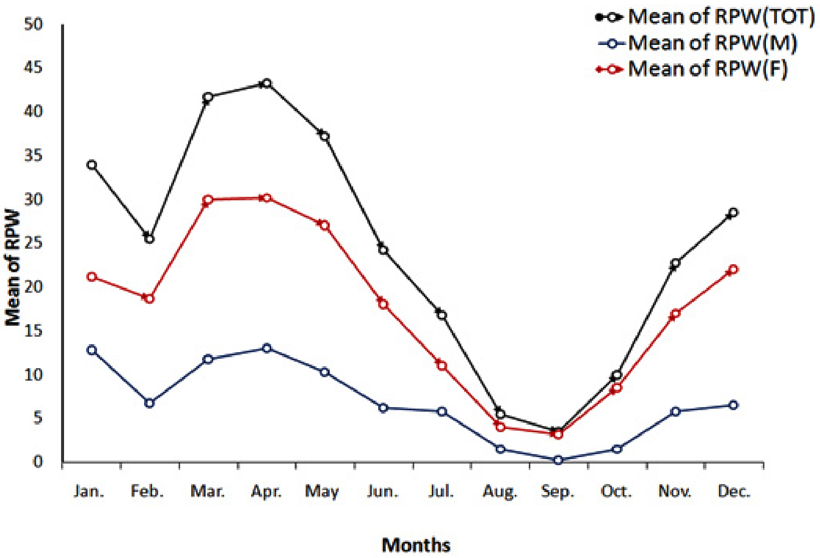

Fig. 3. Activity peaks of the red palm weevil during 2019 in Makkah Al-Mukarramah city

different collection times. Atotal of 1179 RPW were collected from all the traps during the study period started at January to December. The highest population density was recorded during the month ofApril and March with mean population density (43.2 and 41.7) insect / trap respectively. It was the highest significantly compared to that were collected during July, October, August and September, but it does not differ significantly from the numerical densities which collected during May, January, December, February, June and November, as the results showed the presence of numerical differences, but they are not significant (Table 1).

The study recorded two peaks of RPW activity throughout the year. A major peakin April with theaverage density (13.0, 30.2, and 43.2) insect / trap, and a lowest peakin December, where

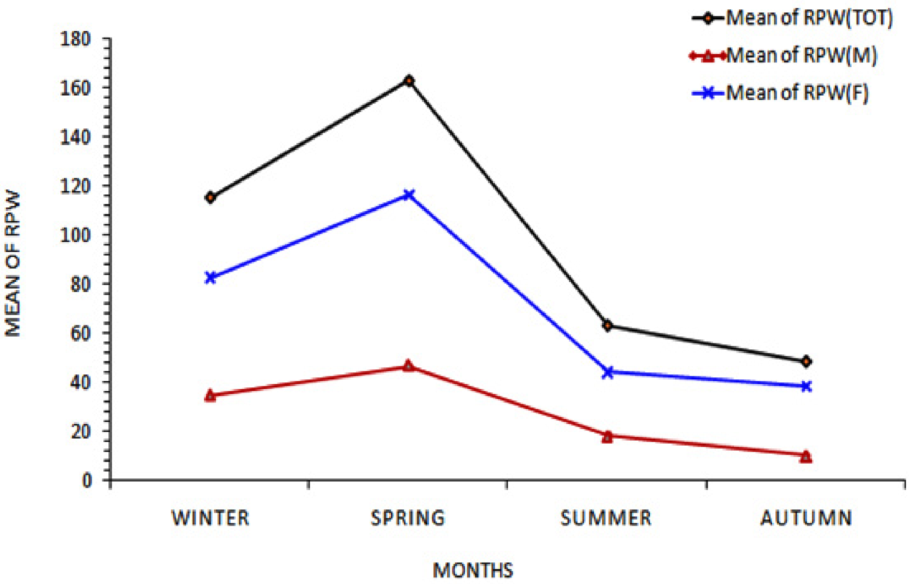

Fig. 4. Seasonal fluctuation of red palm weevil insects in Makkah Al-Mukarramah city

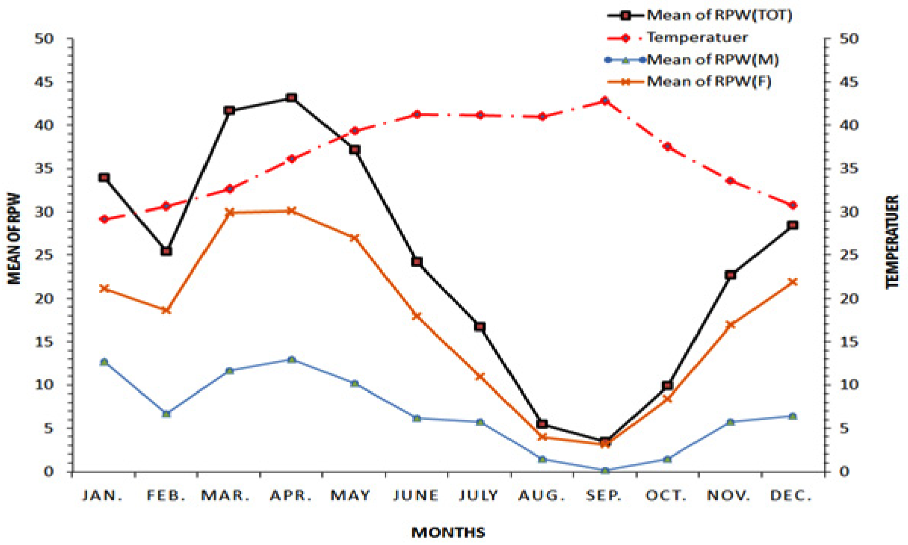

Fig. 5. The effect of temperature on the monthly and dynamic fluctuation of red palm weevil during 2019 in Makkah Al-Mukarramah city

the monthly average was about (6.5, 22.0, 28.5) insect / trap for both males, females and total adults, respectively, Table (1) and Fig.(3).

Statistical analysis results showed that the RPW has significant activity at spring season compared to the other seasons, where the mean number of insects collected (163.0) insects / trap; while the least active for RPW was at autumn season with mean numerical density (63.0 and 48.3) insects / trap.Table (2) and Fig.(4). The results also showed a negative significant correlation between the mean population density of RPW and the temperature; where the correlation strength was (r = -0.318) and the correlation significant (P = 0.0027). The highest density was recorded in April at an average temperature of (36.0) ° C, after that decrease the number associated with an increase in the average temperature during May - August, where the lowest population density of the weevil was recorded at September at (43.0) C. With the gradual decrease in temperatures, a gradual increase in the average population density of the weevil was recorded, reaching its highest average by the end of the fourth quarter of the year (2019) during December at (31.0) ° C (Fig.5).

Also the result showed a positive non-significant correlation between seasonal abundance and relative humidity where the correlation strength (r = + 0.0715) and correlation significance (P = 0.629). Then, at the beginning of the study, a relatively high average density of RPW was recorded in January at an average high relative humidity of 57%. The positive correlation between relative humidity and the seasonal abundance of the weevil appeared during the fourth quarter of the year during October, November, and December, as the traps recorded a gradual increase in the numbers of weevils with a gradual increase

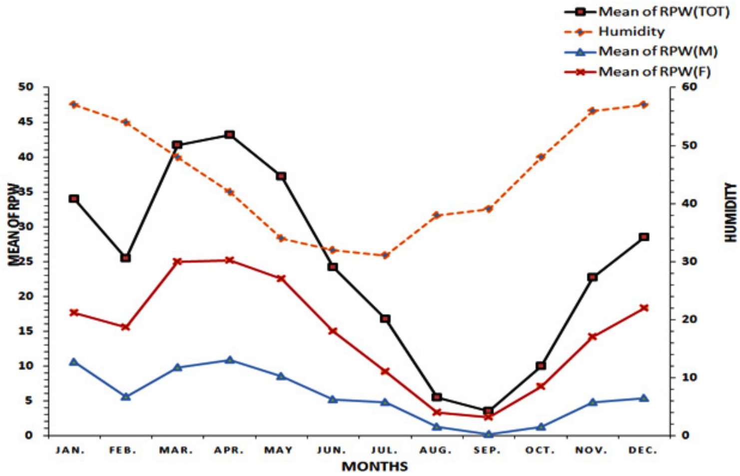

Fig. 6. The effect of humidity on the monthly and dynamic fluctuation of red palm weevil during 2019 in Makkah Al-Mukarramah city

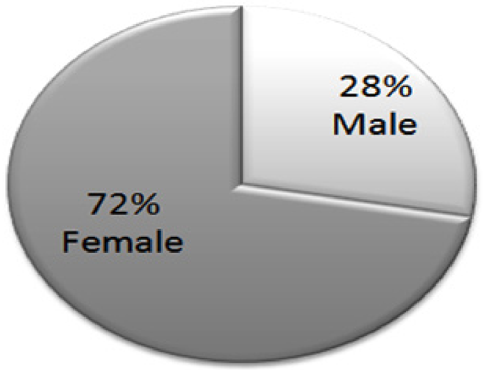

Fig. 7. The average percentage for males and females of the red palm weevil which collected by all traps in Makkah Al-Mukarramah city

The male to female ratio was(1:3). During the study 72% of specimens collected were identified as Females and 28 % were identified as malesTable (3) and Fig.(7).

The color preference for RPW was tested, The result revealed that the black traps were more effective and significantly in attracting RPW than that of other tested colors, where the mean collection of one black trap was (20.3) weevil. Followed by red and white with burlap traps, which didn't differ significantly from each other, as the average that collected by one trap was (13.5 and 10.2) weevil respectively.While the Saudi trap was the least significant in attracting the adults of the red palm weevil, with an average of 4.7 weevil per trap.Table (4) and Fig.(8).

DISCUSSION

In this study, pheromone traps were used to monitor the dynamic fluctuation of RPW during all seasons (spring; summer; autumn and winter), and determine the relationship between

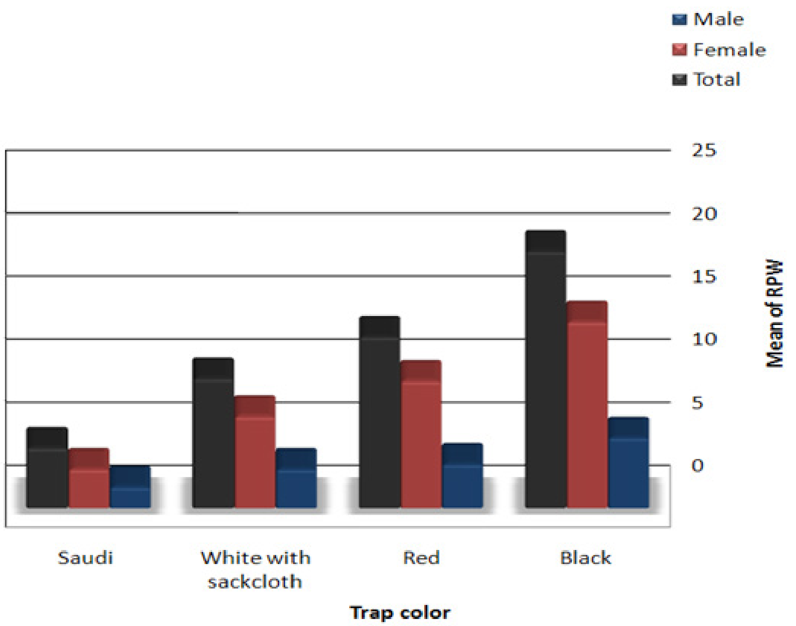

Fig. 8. Temporal changes for red palm weevil under effect of trap color

Table 1. Monthly average of red palm weevil insects in Makkah Al-Mukarramah city during 2019

Months	Male	Female	Mean±S.E Total	Temperature	Humidity
Jan.	$12.75^{AB}\pm 4.4$	$21.2^{ABC}\pm 5.9$	$34.00^{AB}\pm 10.4$	$29.0^{EF}\pm 2.0$	$57.0^{A}\pm 2.0$
Feb.	$6.75^{ABC}\pm 1.3$	$18.7^{ABCD}\pm 5.1$	$25.50^{ABCD}\pm 6.2$	$31.0^{EF}\pm 1.0$	$54.0^{AB}\pm 2.0$
Mar.	$11.75^{AB}\pm 4.4$	$30.0^{A}\pm 6.5$	$41.75^{A}\pm 10.5$	$33.0^{DEF}\pm 3.0$	$48..0^{BC}\pm 2.0$
Apr.	$13.0^{A}\pm 3.3$	$30.2^{A}\pm 7.9$	$43.25^{A}\pm 11.1$	$36.0^{BCDE}\pm 2.0$	$42.0^{CD}\pm 2.0$
May.	$10.25^{AB}\pm 3.3$	$27.0^{AB}\pm 8.2$	$37.25^{AB}\pm 10.8$	$39.0^{ABC}\pm 1.0$	$34.0^{EFG}\pm 2.0$
Jun.	$6.25^{ABC}\pm 1.6$	$18.0^{ABCD}\pm 4.6$	$24.25^{ABCD}\pm 6.2$	$41.0^{AB}\pm 1.0$	$32.0^{GF}\pm 2.0$
Jul.	$5.75^{BC}\pm 1.4$	$11.0^{BCD}\pm 2.5$	$16.75^{BCD}\pm 1.6$	$41.0^{AB}\pm 1.0$	$31.0^{G}\pm 2.0$
Aug.	$1.5^{C}\pm 0.8$	$4.0^{D}\pm 2.4$	$5.50^{D}\pm 3.2$	$41.0^{AB}\pm 1.0$	$38.0^{DEF}\pm 2.0$
Sep.	$0.25^{C}\pm 0.2$	$3.2^{D}\pm 1.7$	$3.50^{D}\pm 1.9$	$43.0^{A}\pm 1.0$	$39.0^{DE}\pm 2.0$
Oct.	$1.5^{C}\pm 1.1$	$8.5^{DC}\pm 3.5$	$10.00^{CD}\pm 4.7$	$38.0^{ABCD}\pm 2.0$	$48.0^{BC}\pm 2.0$
Nov.	$5.75^{BC}\pm 1.6$	$17.0^{ABCD}\pm 6.6$	$22.75^{ABCD}\pm 8.2$	$34.0^{CDEF}\pm 2.0$	$56.0^{A}\pm 2.0$
Dec.	$6.50^{ABC}\pm 1.1$	$22.0^{ABC}\pm 9.8$	$28.50^{ABC}\pm 10.8$	$31.0^{EF}\pm 1.0$	$57.0^{A}\pm 2.0$
LSD	7.1584	17.082	22.94	5.0318	6.1626
P	0.0051	0.0214	0.009	0.0005	0.0001

*The averages which followed by similar letters in the same column, have no significant differences between them at level of significance (0.05) the population density of RPW and the climatic conditions (temperature and relative humidity) ; this is consistent with in that since the beginning of the 1990s, pheromone traps have been used all over the world either to monitor and control RPW infestation in palm farms or to control it[29].

The results showed the presence of RPW throughout the four seasons, with the difference in numerical densities between months in different seasons as well as between months within a single season. This result is consistent with that found by[30 & 31], who recorded the presence of the red palm weevil throughout the year. [20] reported that the population density of RPW is affected by the different climatic conditions, where the captured RPW adults differed significantly between months and during the same month; and the population density was higher in warmer seasons[32], indicated that the weevil was more active in the spring and autumn season, specifically in April and November respectively in Egypt.

The results of this study were also identical to that reported by[33], which the highest number of adults of RPW in spring season in March, April and May, in KSA and Egypt was. He also added that RPW had two activity peaks, the first one was in May and the second was in November, and the lowest density of weevil was in August. In the Middle East, the high seasonal activity of RPW was recorded during the months of March, May, September and October[34 & 35].

These seasonal changes in temperature and relative humidity reflect the temporal variation in RPW numbers collected by pheromone traps[36].

Table 2. Seasonal fluctuation of the red palm weevil insects in Makkah Al-Mukarramah city during 2019

Seasons	Mean ±SE Male	Female	Total
Winter	34.6 ^{AB} ± 8.1	82.6 ^{A}±3.9	115.33 ^{AB} ±11.5
Spring	46.6 ^{A} ± 3.1	116.3 ^{A}±4.1	163.0 ^{A} ±7.2
Summer	18.0 ^{BC} ±6.0	44.0 ^{B}±16.1	63.0 ^{BC}±21.9
Autumn	10.0 ^{C} ± 6.6	38.33 ^{B}±16.0	48.33 ^{C} ±22.6
LSD	20.467	38.276	55.97
P	0.0131	0.0049	0.0055

*The averages which followed by similar letters in the same column, have no significant differences between them at level of significance (0.05)

Table 3. The average of male and female red palm weevil that collected by all traps in Makkah Al-Mukarramah city

Sex	Mean±S.E
Male	13.6 ^{B}± 2.0
Female	35.1 ^{A}± 4.0
LSD	9.07
P	0.0001

Table 4. Red palm weevil numerical density under effect of trap color

Trap color	Mean ± SE Male	Female	Total
Red	3.4 ^{B} ± 0.6	10.0 ^{B} ± 1.3	13.5 ^{B} ± 1.9
White	3.0^{BC} ± 0.5	7.2 ^{B} ± 1.0	10.2 ^{B} ± 3.1
Black	5.5 ^{A} ± 0.9	14.7 ^{A} ± 1.5	20.3 ^{A} ± 2.3
Saudi	1.6 ^{C} ± 0.4	3.0 ^{C} ± 0.5	4.7 ^{C}± 0.8
LSD	1.8331	3.3969	4.8409
P	0.0007	0.0001	0.0001

This difference in seasonal abundance is due to the influence of climatic factors on the activity of RPW, as many environmental studies have indicated that both of environmental parameters (temperature and humidity) affect on the activity of RPW. This is confirmed by the results of the study that conducted by[24] which agreed with the results of the present study, where the seasonal variations of RPW abundance due to climatic conditions and added that the red palm weevil tends to rise during the spring season.

The results of their study also concluded that there was a positive relationship with high statistical significance between the number of RPW that was captured and the temperature, while a negative relationship was observed between the numbers of the weevils and the relative humidity, which is consistent with the results of the current study, as well as with what[37] that there is an effect of environmental factors on the population density of red palm weevil, as they found a direct correlation between the numbers of the weevil and the temperature and an opposite relationship with relative humidity.

The importance of environmental factors in general and temperature and relative humidity in particular on the living organisms is not hidden, as they are considered among the limiting factors for the distribution and spread of living organisms in different environments due to their joint effect on the vitality and activity of living organisms.

Each species of insect has a temperature range in which it can live, and within this range there is an optimum temperature at which the insect activity is at its peak; also within this range there are hot and cold dormancy zone , in which the temperature increases or decreases than optimum temperature, so insect's activity begins to decline until it stops as a result of beyond the extent temperature that the insect can tolerate, which leads to its death. The same is true for humidity, as it affects the biological processes of the insect through a water imbalance, and the effect of humidity is more clear with high temperatures[38].

The insect loses water in response to the increase of temperature in the surrounding environment. The loss process done through the spiracles; cuticular and by excretory system, but 90% of transpiration is via the cuticle, this layer consists of three layers one of them is epicuticle and the lipid layers that present in its structure are one of the main substrates that hinder water loss.

The results of[39] study shown the physiological basis to explaining the effect of drought on RPW; they isolated and identified ten hydrocarbons compounds the weevil cuticle. Seven of them were un-branched saturated n-kinases (n-Heptadecane; n-Nonadecane; n-Heneicosane; n-Tricosane; n-Pentacosane; n-Nonacosane and n-hexatriacontane) and they represent 75%, while the fatty alcoholic compound (3- (E) Eicosanol) ; the ester compound (1-Henicosyl formate) and the unsaturated alkene compound (Tricosene) represented 17-25% of the total hydrocarbons. [40] added that at a rather high environmental temperature, most of the saturated un-branched hydrocarbons take a solid crystalline form and thus prevent water loss,also the study results that carried out by[41] showed the temperatures which required to dissolve these compounds, where the temperature for most saturated un-branched hydrocarbons ranged between (41 - 76) C°, which explains the ability of red palm weevil to prevent the water loss from its bodies under high temperature and low humidity. As for the rest of the unsaturated compounds, their melting point is less than 21C °. [39] added that, based on previous studies, 25% of the hydrocarbons in RPW cuticle are in liquid form at temperatures below 20C ° , where they act as large pores that precipitate through the wax cover. Thus, the large rate deposition of these compounds in the cuticle of RPW may be responsible for the high water loss rates that are attributed to insect death under high temperature and low relative humidity.

Furthermore, the temperature and relative humidity have an effect on the growth and development of RPW, starting from eggs laying; hatching success; larval development and ability to emerge as an adult insect, as mentioned by a lot of scientific research[42; 43; 44; 45; 46 & 47]. This explains the relationship of tested climatic factors to the dynamic fluctuation and seasonal abundance of red palm weevil.

In addition, the present study aimed to determine the sexual ratio of adults red palm weevil that captured by pheromone traps during the study period.The results showed significant differences between the mean number of males and females, where females were the most significant, this agree with many scientific studies[16; 33; 48; 49; 50; 51; 52; 53; 54 & 55].

In a study conducted during 2018 and 2019 to compare the effectiveness of two types of traps used to control RPW in Egypt, the results showed that there was no significant difference between the total number of RPW collected by the two tested traps. While there was a significant difference between the number of males and females, where the sexual ratio between males and females was (1: 1.43 and 1: 1.94) during 2018 and 2019, respectively,[56]. In another experiment by[37]. to follow up the red palm weevil, it was found that the number of females collected exceeds the number of males, with ratio of males to females (3.1: 1).

In the current study, the increased number of females may be due to they may have a higher sensitivity to aggregation pheromone than males and this has been confirmed by previous studies, as mentioned by[57] where they found that females of RPW respond to aggregation pheromone more than males.[58] also indicated that females of RPW have more basioconic sensillae on antenna than males, as it is known that these basioconic sensillae are sensitive to aggregation pheromone[59].

Also, as a result of feeding the larvae and crowding the palm with the different stages of RPW , the host becomes of poor quality. Thus, it is necessary to leave the this host and search for another host for laying eggs to ensure continuity of survival; perhaps the reason is that the females search for males for mating, so the females are sensitive to the aggregation pheromone, which explains the increase number of females over males in pheromone traps.

Or perhaps reason of more females over males is due to their higher levels of activity. This is confirmed by previous studies and current result in that the majority of captured females are young and fertile[49 & 60], which enhances the use of pheromone traps as a tool of monitoring and controlling red palm weevil infestation, because it reduces the numerous densities as a result of captured fertile females thus, the infestation decreases through lack of laying eggs, which serves integrated management to control red palm weevil.

In many scientific studies and researches, focus has been on the design and color of the trap; the pheromone and the kermon which used in it and the duration of their change as variables affecting the success of RPW control process using food bait pheromone traps[55 & 61].

In the ourstudy, the color preference of RPW was tested, and the results showed that black-colored traps were more effective and more significant in attracting red palm weevil adults compared to the tested colors, and this is in agreement with many scientific studies[36; 54; 62;63 64 & 65].

The main reason for red palm weevil's attraction to black trap is that the black color wavelength spectrum is very similar to the palm tree fibers when analyzing the spectral reflectance of the tested colors and some plant tissues, which leads to the attraction of the weevil adults to black traps. More compared to other colors[66]; or due to the black color absorbs more sunlight compared to other colors which leads to a high temperature in black traps, that might cause greater pheromone release, which result in increase insect captures[67].

CONCLUSIONS

Environmental studies concluded that the RPW was present in traps throughout the year, The study recorded the highest population density during April and March, and two peaks of weevil activity in April and in December. The spring season witnessed significant activity of weevil; with a negative significant correlation between the mean population density of weevil and the temperature; and a positive non-significant correlation with relative humidity. Also the females were the highest density significant Compared with males. The black traps were more effective and more significant in attracting weevils adults than the tested colors.

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