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Assessment of Environmental Factors Affecting Red Palm Weevil Dissemination and Their Implications for Raw Material Supply Chain Security in the Food Industry (Case Study: Safwan District, 2023–2024)

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ABSTRACT

The present study aimed to elucidate the impact of some environmental factors (temperature and relative humidity) on the sexual ratio of males and females of red palm weevil in 6 locations of Safwan District in Basra Governorate, southern Iraq, using dry pheromone traps (Electrap) in 2023 and 2024. All studied locations had red palm weevils throughout the year. There were three peaks of monthly adult fluctuation in population numbers during May, December and April (4.38, 4.25 and 4.19 insects per trap, respectively) which occurred over the two years. Densities of 1.08 insects per trap, 1.19 insects per trap and 2.06 insects per trap were recorded in 2023 in February, September and October, respectively, when insect densities were the lowest. Four high periods were detected in 2024, April (6.96 insects per trap), November (6.44 insects per trap), May (6.23 insects per trap), and October (6.17 insects per trap). The lowest densities occurred in January, December, February, and July, when the densities were 1.96, 2.06, 2.98, and 3.35 insects/trap, respectively. Maximum insect population was recorded in eastern Safwan (6.09 and 10.28 insects per trap in 2023 and 2024, respectively) followed by Kharda region (1.26 and 2.57 insects per trap in 2023 and 2024, respectively). It was found that higher density (3.19 and 5.39) insects/trap was recorded for female population than the male population which recorded density up to (2.24 and 3.60) insects/trap, with an average sex ratio of 41.27 and 40% for the year 2023 and 2024, respectively, for females while it was 58.72 and 59.97% for males. This study does not include direct measurements of food safety endpoints (e.g., pathogen or contaminant levels in dates). The results only apply to the dynamics of the pests, and aimed to support integrated pest management strategies.

1- INTRODUCTION

Phoenix dactylifera L., commonly known as date palm, is a fruit tree that belongs to the palm family, Arecaceae, and is one of the oldest and most significant desert fruits trees in subtropical areas [1, 2]. It is endemic to Iraq, Saudi Arabia, Iran and parts of North Africa [3, 4]. The socio-economic importance for date palms includes their nutritional and environmental value, especially in the Arab world [5]. It is found that in most governorates of Iraq, cultivation of date palm is widespread, one of the most important date-producing governorates is Basra [6]. All parts of the palm are susceptible to a number of pests, especially those affecting the trunk and vascular system [7], leading to a decrease in date production [8]. The most threatening of all these pests is the red palm weevil *Rhynchophorus ferrugineus* (Olivier) (*Coleoptera: Curculionidae*) [9, 10] which is on the economic list of pests of great importance worldwide [11, 12] with high cost of control and replacement of infested palms [13]. A beetle, this species is a superb flyer, highly fertile female (after fertilization), and has multiple generations annually [14, 15]. It is regarded as the most devastating date palm pest in the world, and is often present without being detected until extensive damage has been caused [16]. This is an all-year insect of the plant, common in all areas of the world [17] which gives rise to larvae that penetrate the trunk. Red palm weevils are known to eat the tissue of palms [18]. The first record of its presence in Iraq as an introduced pest is from December 2015 in the Safwan district of Basra Governorate [19, 20]. This invasion has grave potential threats particularly as date palms are the favourite species of the red palm weevil [21].

Some of the most critical methods to track populations of the red palm weevil are pheromone traps, and assessing the contribution of environmental factors to the spread of RPW [22]. This method will create a durable and readily available solution, and minimize the possibility of developing pest resistance [23]. Overlapping generations of the pest are found in the late stages infestation which damages the biological tissue of the palm-trunk and will kill the palm at the end of the infestation [24]. Chemical pesticides are used preventatively and curatively. Phyreomone trap is a method of controlling the insect. In this context, ferrugineol (4-methyl-5-nonanol) was discovered and first produced in the early 1990's [25, 26] and is the pheromone released by the males of red palm weevils. Reduction of pest populations in pest management using monitoring and mass trapping has resulted in adoption of this aggregation pheromone. [24] Successful use of pheromone traps has been reported in a number of countries [27].

Some scientists noticed that environmental changes like temperature and relative humidity affect the spread and development of red palm weevil [28, 29, 30]. There have been varying numbers of adult red palm weevils. Two seasons of pheromone trapping was used to collect the insects. There were 4 peaks in insect population during the months of March, May, Sept & Dec respectively and the infestation rate of palm trees went down 100% as compared to the years in which the chemical pesticides were used as control. This suggests pheromone traps could be useful for improving control of this economic important insect species, as they are more attractive to females than to males [31]. On a general basis the pest was reported as being present throughout the year and in 2009 and 2010 the following four peaks of adults in each instance were reported: April, June, August and November with a ratio of females to males two to one each time. The environmental factors significantly affect the adult insect population, which consists of temperature having significant positive effect and relative humidity having significant negative effect [32]. Another observation was that the number of adults increased during the summer period than in the winter period. The highest densities occurred in April, May and June. The figure of 12 to 14°C is a good estimate of the growth temperature range for the red palm weevil. During this period of colder winter months (December-January) their populations tend to be lower, reflecting lower mean daily temperatures. The increased numbers in the warmer summer seasons are believed to be due to adults emerging from the cold winter which has delayed their development. There are twice as many females as males in the trap [33].

The goal of this study was first to see where adult red palm weevils are spreading and make an estimate of their population density via pheromone traps, then to evaluate how environmental factors will affect this spreading. The knowledge of insect's active period and peak during the study period is important for the time of action to be taken for their control and in making full use of IPM programmes to ensure the protection of the palm trees in Safwan district. This study only looks at the pest population dynamics and not at food safety endpoints due to dates being an important agricultural crop. No food safety, raw material quality or stability of their supply chain is made available.

2- Materials and Methods

Study Area and Trap Distribution

An investigation was conducted over two successive years 2023 and 2024 in the Safwan district of the southwest of the Basra Governorate, related to the spread of red palm weevil (*Rhynchophorus ferrugineus*) species. This study was carried out in the areas of Sanam, National Safwan, Al-Hadama, Al-Kharda, East Safwan and South Muwailihat. For each area, six date palm farms were chosen and one pheromone trap was placed in each farm, amounted to thirty-six pheromone traps that were spread around for use during the study.

Design and Construction of a Trap

The red palm weevil activity and density was monitored with a dry pheromone trap (Electrophores). Trap was built to capture and kill adults. The compound was filled in a glass chamber with a pheromone solution that released into the air within a radius of 25 m. Both males and females were attracted to the pheromone through their antennae and into the trap. The pyramid shape of the trap made it easy for the rats to get into and the sleek interior walls and the bristles lining the hole that they had to exit the trap kept them trapped. Inside the trap, insects die of dehydration and the heat caused by the colour of the trap. The Rhyfer 400 pheromone (Tripheron, Germany) was used in the trap, and the pheromone container was replaced every month to maintain its effectiveness [34].

The Red Palm Weevil Adults were monitored.

To track the spread of the insect, the insect sex (Male and Female) distribution, time (2023 and 2024) (Monthly intervals) and geographic (Six areas of Safwan district) were taken. Trapping of adults was performed by taking the adult cohorts from the pheromone traps, counting them and marking the insects as male or female at the time of sampling each month.

Environmental Factor Data

The data of the environmental factors were collected throughout the study period of 24 months (2023-2024) from the Agricultural

Meteorological Center in Al-Burjasiya station in Basra Governorate under the Iraqi Ministry of Agriculture. Here the following data were collected: Minimum temperature, Maximum temperature, Average temperature, Relative humidity, Minimum relative humidity, Maximum relative humidity and Average relative humidity (%).

Statistical Analysis

To this effect, multiple correlation analysis (r) was used to explore the relationship between the spread of red palm weevil and data on the environmental factors. Data were analyzed with SPSS and analysis of variance (ANOVA) and least significant difference (L.S.D.) test was used to compare data sets [35, 36].

3- Results and Discussion

Red Palm Weevil Infestation in 2023

A statistical analysis (Table 1) identified three peaks in red palm weevil infestation in 2023 with highly significant differences found between each period, infestation areas and between insect sexes. The highest densities (4.38, 4.25 and 4.19 insects per trap) were recorded in April, May and December, respectively, showing fluctuations in infestation. The lowest density (1.08, 1.19 and 2.06 insects per trap, respectively) were attached in February, September and October. There were substantial differences among areas with infestation with the highest mean (6.09 insects per trap) being in the East Safwan area and the lowest mean (1.26 insects per trap) being in Al-Kharda area. Sex ratios were apparent with each female insect averaging 3.19 insects per trap whereas a male insect would average 2.24 insects per trap. The ratio of male to female was 4 to 5, that of male to female ministers was 48.75:51.25.

There was clear existing interaction effect of the factors studied as compared to the individual effect of each factor. Generally, the highest female density (15.50 insects per trap) was recorded at East Safwan region and the lowest female density (0.25 insects per trap) was recorded at Al-Kharda and South Muwailihat regions in May and February, respectively. Male populations were highest in June reaching an average of 8.75 insects per trap in East Safwan before declining to zero; no insects were caught in Sanam during February, August, September and October, and in Al-Hadama and South Muwailihat in February and September, respectively.

Table 1. Red Palm Weevil *R. ferrugineus* Infestation dissemination for 2023

Months 2023	Sex	Area						Average
		Sanam	Safwan North	Al-Hadama	Al-Kharda	Safwan East	Muwailihat South	
January	Male	0.75	0.50	1.50	1.25	5.00	2.75	2.44
	Female	2.25	1.75	2.25	1.75	7.50	2.00	
February	Male	0.00	1.00	0.00	0.50	2.25	0.00	1.08
	Female	2.00	2.25	1.50	0.25	3.00	0.25	
March	Male	1.25	2.00	2.25	0.25	4.00	0.50	2.85
	Female	5.25	4.50	4.50	2.25	5.50	2.00	
April	Male	2.00	3.25	5.75	1.25	6.75	4.00	4.19
	Female	2.75	4.00	4.50	1.25	8.75	6.00	
May	Male	1.00	2.75	4.00	0.75	5.25	4.50	4.38

	Female	2.75	4.00	4.50	0.50	15.50	7.00	
June	Male	0.75	0.75	4.50	3.75	8.75	2.00	2.83
	Female	2.50	1.75	1.75	0.50	5.25	1.75	
July	Male	1.25	1.00	2.25	1.50	3.50	0.50	2.06
	Female	2.00	1.00	1.50	0.75	6.00	3.50	
August	Male	0.00	1.25	2.50	2.50	7.75	1.75	2.44
	Female	0.50	0.50	2.00	0.25	7.00	3.25	
September	Male	0.00	0.75	0.25	0.00	3.00	1.00	1.19
	Female	1.25	2.00	2.25	0.75	2.00	1.00	
October	Male	0.00	1.25	1.50	1.00	3.50	2.25	2.06
	Female	1.25	3.50	1.75	1.00	5.25	2.50	
November	Male	2.00	1.25	2.75	0.50	7.00	1.00	2.83
	Female	2.00	2.75	3.50	2.50	6.25	2.50	
December	Male	1.25	2.75	4.50	2.75	7.25	0.75	4.25
	Female	4.50	4.75	5.75	2.50	10.25	4.00	
Average		1.64	2.14	2.81	1.26	6.09	2.37	2.72
L.S.D (0.05)		Sex= 0.074		Area= 0.181		Months= 0.128		Total interaction 0.626
		Sex/area int.= 0.256		Sex/month int. 0.181		Area/month int.= 0.443		

The results of the either sex of insect bothpent—the month of 2023 showed a significant difference. The highest average of females (5.71 insects per trap and 5.29 insects per trap, respectively) were caught in May and December, while the lowest average (1.54 insects per trap) in February and September. The greatest number of specimens per trap were recorded in both April (3.83 males per trap) and June (3.42 males per trap) and the least number of insects per trap in February (0.63) and September (0.83) (Figure 1).

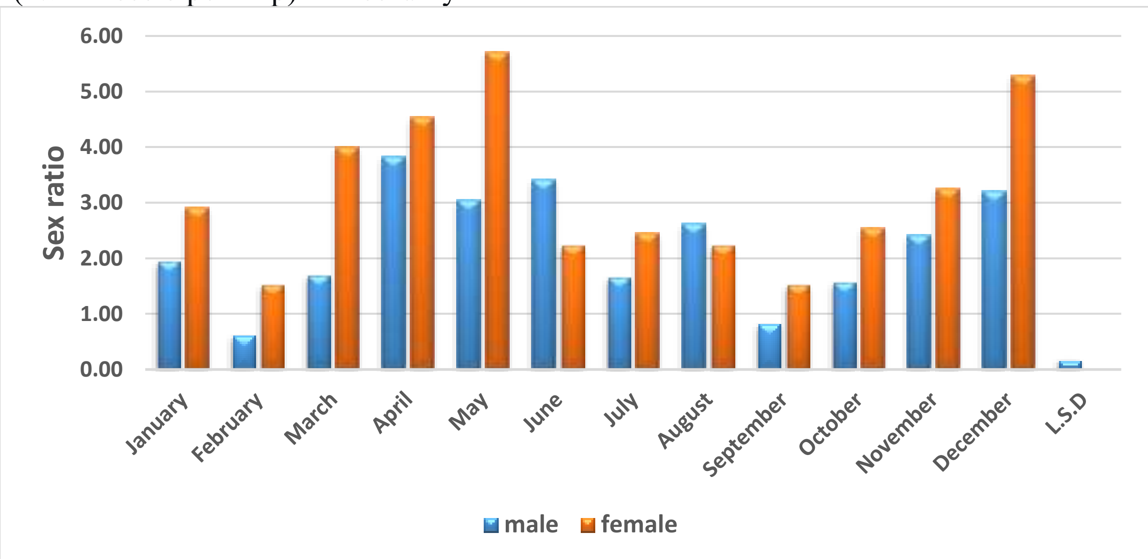

Figure 1. Sex ratio of the red palm weevil *R. ferrugineus* monthly distributed during the 2023

Increased population density during the warmer summer months is possibly related to increased activity of flights and/or mating, brood completing their development in the winter and environmental factors (temperature and relative humidity). The excess occurrence of the red palm weevil in the East Safwan region could be a consequence of the relative low level of palm tree infestation caused by their advanced age (15-20 years). This enables artificial pheromones and kairomones to be more attractive on adult weevil traps. These results are in line with the results obtained by Manzoor et al. [37] who reported three to four circumlocations of the spread of red palm weevil, with the highest during April (18.76, 24.42, 11.26 and 8.16 insects / trap), May (15.34, 23.44, 9.24 and 5.14 insects / trap) and June (14.11, 21.22, 7.31 and 5.08 insects / trap) in four regions of Pakistan namely Punjab, Sindh, Khyber Pakhtunkhwa and Balochistan, respectively. This present study also coincided with that of Asiri [17] which showed that spread of red palm weevil takes place throughout the year and the four peak occurrence was in March, October, May and July of 2021, followed by another spread in March, May and June, and another occurrence of the pest in mid-September 2022.

The collection of the adult insects in pheromone traps over the six study years (2017–2022) showed a fluctuation in the number of adults (Alderawii et al., 19). The numbers of insects per trap were much higher in May (2.06 insects per trap) and April (2.47 insects per trap), and low in January (0.51 insects per trap) and December (0.54 insects per trap). Capture of adult red palm weevil in pheromone traps peaked in the summer months than in the winter months in Egypt [33]. The higher percentage of female red palm weevil collected on pheromone traps is probably due to females being more active in the field than males. The results of the present study agree with those obtained by Bharath et al. [38] which found that all the experimental sites had relatively higher females than males with the highest ratio of 1.34:1 (female to male).

The area is at risk of red palm weevil infestation in 2024.

Four peaks in 2024 were observed during red palm weevil infestation, which shows significant variations among the locations of infestation, sex and infestation time. The highest average densities (6.96, 6.44, 6.23, 6.17 insects/trap, respectively) were observed in April, November, May and October while the lowest densities (1.96, 2.06, 2.98 and 3.35 insects/trap, respectively) were observed in January, December, February and July. In terms of infestation area, the highest average (10.28 insects per trap) was observed in Safwan East, followed by Muwailihat South (5.52) and the lowest average (1.90) was recorded in Sanam and in Al-Kharda (2.57). Typically, there was a great variation in the infestation rates with the female rate being 5.39 insects/ trap (59.97%), whereas the male rate was 3.60 insects/ trap (40.03%). The interaction of the study factors showed significantly different results, and the highest infestation rate by female (23.75, 19.00 and 17.50 insects per trap) was obtained in East Safwan region for the months of April, March and May respectively The insect did not occur at all in Al-Kharda region in July. The highest infestation rate among the males was recorded in the East Safwan region April (15.25 insects/trap), decreasing gradually and becoming zero in the Sanam region in February-July.

At moderate temperatures, the infestation rate rises while at high or low temperatures (sitting in the sun and on shade), the infestation rate significantly decreases as the adult insect becomes dormant and enters in a palm tree or soil in search of shade and shelter. This is in agreement with previous investigations which have recorded monthly variation in the distribution of adult weevils collected in pheromone trap sets set up in six locations in Ras Al Khaimah, UAE. Spread began to gradually increase, reaching a maximum in May, then April, in areas three, two, and one, respectively, and decreasing to its lowest peak in January and December, respectively, and January in area one [25]. At 42.8°C average daytime temperature, population of Red palm weevil decreased [39].

The study also revealed that there was a decrease in red palm weevil population with 42.8°C average temperature during the day. The low infestation rate in the Al-Kharda area was explained by the high infestation rate of the red palm weevil which resulted in high production of the natural aggregation pheromones (AP) secreted by males and the kairomones emitted from infected palms. Its natural sex attractants and kairomones are more attractive to males than the artificial pheromones and kairomones that are used in traps. Volatile chemicals from infected palm trees that comprise the fermentation products of palm sap, known as kairomones, that attract the red palm weevil were mentioned by Kal Shoven [40].

Based on the study of Saleh et al. [41] the highest population density occurred in November and the lowest in December. They saw two peaks in the populations of these insects—the first between October 9 and 12.25 (9–12.25 insects per trap) and the second between April and May (7.75–9.75 insects per trap). The density of this adult weevil dropped in December and January to 0.75 and 2.75 weevils/trap, respectively. Adult insects were captured in May and November with the maximum numbers in these months being 6.33, 6.00, 5.33, and 5.00 for four locations, and 5.00, 4.66, 4.33, and 4.00 for the adult insects in these months, respectively. The number changed in following periods between the starting of April and the end of November, and with the lowest level of 0.53 insects per trap during July and August [42].

Table 2. Red Palm Weevil *R. ferrugineus* Infestation dissemination for 2024

Months 2023	**Sex**	**Area**						**Average**
		Sanam	Safwan North	Al-Hadama	Al-Kharda	Safwan East	Muwailihat South	
January	Male	0.50	0.50	1.00	1.50	3.50	0.25	1.96
	Female	3.00	3.00	1.50	0.50	5.00	1.25	
February	Male	0.00	0.00	3.00	3.00	6.25	1.25	2.98
	Female	1.50	1.50	1.50	3.50	6.00	2.50	
March	Male	1.00	1.00	2.25	5.25	14.50	2.00	5.88
	Female	5.00	5.00	5.00	5.75	19.00	2.25	
April	Male	1.25	1.25	7.25	4.00	15.25	1.50	6.96
	Female	4.25	4.25	5.00	3.50	23.75	9.25	
May	Male	2.50	2.50	5.75	2.50	10.75	2.50	6.23
	Female	7.25	7.25	5.00	3.25	17.50	5.00	
June	Male	1.50	1.50	2.00	1.50	8.50	4.00	4.38
	Female	0.75	0.75	2.25	2.50	16.50	5.75	
July	Male	0.00	0.00	1.75	0.25	7.50	5.00	3.35
	Female	1.00	1.00	3.00	0.00	10.50	6.75	
August	Male	0.50	0.50	2.25	1.75	6.75	5.50	4.00
	Female	2.00	2.00	3.50	1.50	12.00	7.50	
September	Male	0.50	0.50	5.00	1.00	4.50	6.25	3.54
	Female	1.00	1.00	6.00	1.50	3.50	9.50	
October	Male	1.25	1.25	2.50	2.50	10.50	13.25	6.17
	Female	1.75	1.75	5.00	2.50	13.00	17.25	

November	Male	2.00	2.00	5.00	3.50	9.25	9.00	6.44
	Female	3.75	3.75	6.25	7.00	15.75	10.75	
December	Male	1.50	1.50	0.25	1.50	3.00	1.25	2.06
	Female	1.75	1.75	1.00	2.00	4.00	3.00	
Average		1.64	1.90	1.90	3.46	2.57	10.28	5.52
L.S.D (0.05)		Sex= 0.074		Area= 0.199		Months= 0.199		Total interaction 0.691
		Sex/area int.= 0.282		Sex/month int. = 0.199		Area/month int.= 0.489		

The densities of the female and male populations observed in 2024 were highest each month and the resulting impact of months on insect sex were as follows: 8.54 insects per trap of females and 5.38 insects per trap of males were observed in April, 7.71 and 5.17 respectively in November, and 7.58 and 4.88 respectively in May. However, female numbers dropped down to 2.46, 2.58 and 3.25 and male numbers to 1.46, 1.54 and 2.71 insects / trap in January and February respectively (Figure 2). Possible reasons for the attraction to pheromone traps include higher activity of female in the field than males due to egg-laying activity [43] or the greater number of basal receptors on the antennae of female to males [44]. However, for the two years of study Arafa et al. [45] found that the adult female count in pheromone traps was higher than males with the first year of study showing 45.27% males and 43.60% females, and the second year 43.60% males and 56.40% females, respectively. Likewise, Basahih et al., [46] found that in Wadi Hadhramaut of Yemen, females collected through pheromone trapping outnumbered males and the ratio of females to males was 1:2. Junejo et al. [47] found that the total number of adult insects captured was 18 females (60% sex ratio) and 12 males (40% sex ratio), equivalent to a ratio of 2:3 (males:females).

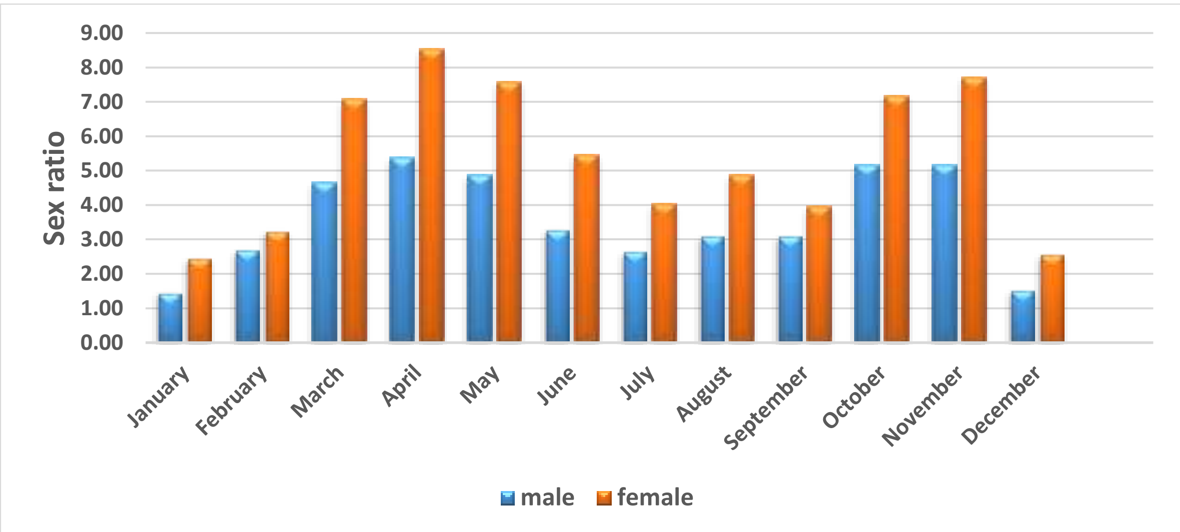

Figure 2. Sex ratio of the red palm weevil *R. ferrugineus* monthly distributed during the 2024

Impact of Environmental Factors on Insect Spread

The findings demonstrate the importance of environmental factors to the spread of the red palm weevil and emergence from damaged palm trees to re-infect new palm stands in farms of Safwan district. Simple correlation analysis was performed between the average temperature and spread of the red palm weevil based on the results of the analysis, it is found that there are statistically significant relationships. (Figures 3, A and B) In terms of correlation, the temperatures had a positive correlation for both 2023 (R = 0.17) and 2024 (R = 0.43) at Safwan district. Relative humidity also was beneficial with Pearson's correlation coefficients of R = 0.22 in 2023 and R = 0.26 in 2024, respectively (Figure 3, C & D).

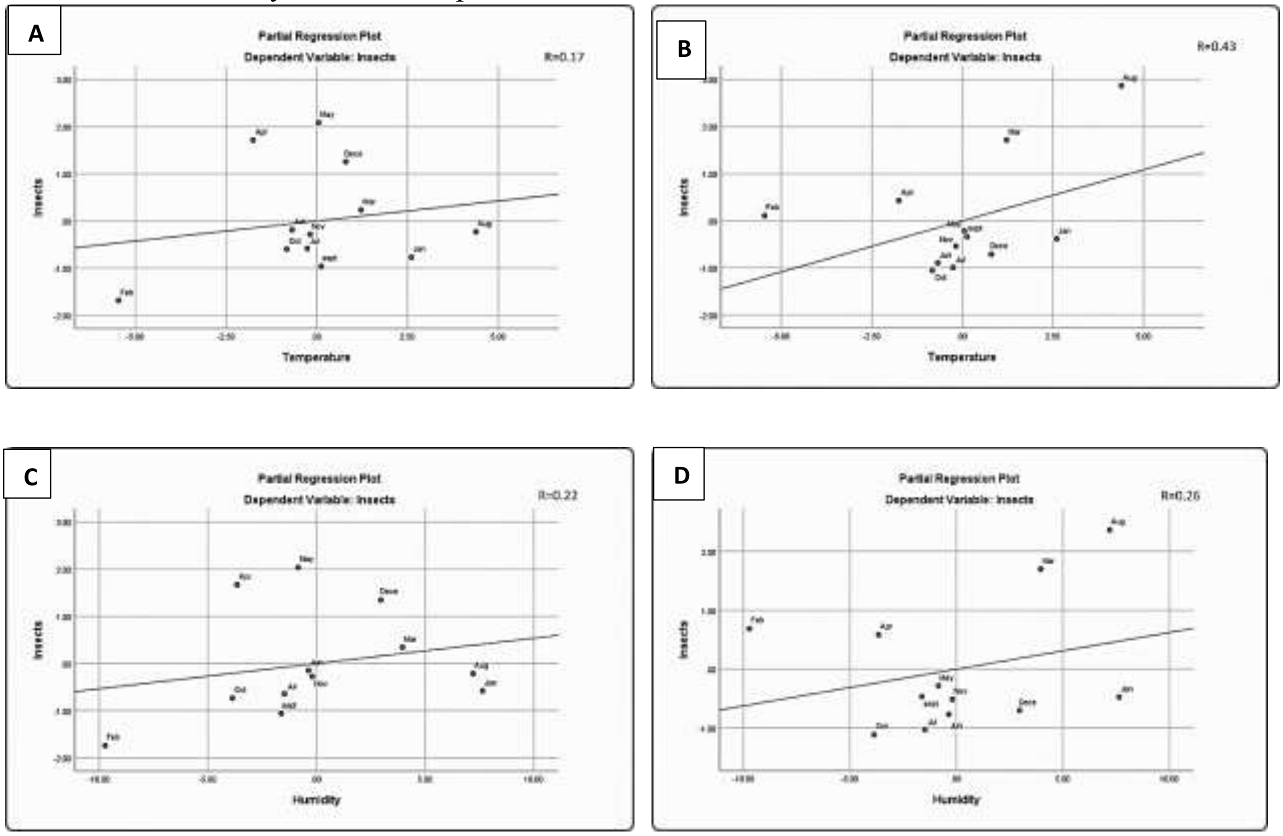

Figure 3: Effect of temperature (A and B) and relative humidity (C and D) on spread and population density of the red palm weevil during 2023 and 2024, respectively.

The outcomes of this study support earlier studies that have revealed the impact of environmental considerations (temperature and relative humidity) and identified positive and negative correlations between these factors and attraction of the red palm weevil [47]. The red palm weevil was observed to have different effects on day-relative humidity and air temperature during 2021 and 2022. The average daily air temperatures are also mentioned as the best indicator to the changes in insects populations. Over two years the average daily temperature was found to have highly statistically significant positive correlations with the number of red palm weevils, r = 0.62 and 0.67 respectively. Over the same two years weak non-significant negative correlations were found between the average daily relative humidity and the insect populations (r = 0.45 and 0.56, respectively) [17]. Manzoor et al. [37] noted a positive correlation between temperature and densities of red palm weevil in Pakistan and a negative correlation between relative humidity and spread of the insects in the country. Arafa et al. [45] show in Egypt, in the Sharqia Governorate how environmental factors affected adult red palm weevil spread by simple correlation and regression. The correlations were positive for max temps, min temps, and average temps and for average relative humidity in the 2022 year were highly statistically significant. The correlations were slightly positive for temperature, and weakly negative for relative humidity in 2023, however, statistically significant.

4-Conclusion

Based on the findings from monthly field monitoring conducted in 2023 and 2024 in Safwan district, statistical analysis showing highly significant differences among the three factors of months, regions and sex ratios, it can be deduced that the population dynamics of the red palm weevil exhibited a very clear seasonality but were continuous throughout the years of 2023 and 2024. This indicates that the pest is established and relatively stable in the study area. In general, the insect abundance was greatest in the spring and late autumn, with moderate temperatures reasonably well correlated with insect abundance. The results also demonstrated that there was a numerical superiority of females over males in all locations, with generally 60% females and 40% males. This means how effective pheromone traps are when being used to attract females, which is key to an integrated pest management program. East Safwan had the highest population density for both years, while there was a significant drop in population density in Al-Kharda. This is due to differences among the environments and farms in pheromone attractiveness, severity, and orchard makeup. These differences can be attributed to the age of the trees, planting density as well as availability of the natural kairomone sources provided by infested trees. From this research it can be concluded that dry pheromone traps (Electrophores) are very effective tools for both early warning and monitoring, and help determine the pest's seasonal pattern and pinpoint important time windows when control efforts can be made. The results of this research have important implications in the field of date industry because it is crucial to control pest to guarantee the stability of date supply chains and the quality and safety of raw dates used in date food products production. The results of this study will assist in understanding the dynamics of red palm weevil populations in southern Iraq and help develop IPM strategies. The results of this study were not reported for food safety endpoints (such as levels of pathogens and contaminants in dates). Future studies are required that also use direct food safety measurements before implications to the food industry could be identified.

Ethical Approval

This study did not involve human participants or animals. All experimental procedures were conducted in accordance with institutional and laboratory biosafety guidelines.

Conflict of Interest

The authors declare that they have no conflict of interest.

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This research received no external funding.

Data Availability

All data supporting the findings of this study are available within the manuscript.

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