ELUCIDATING BIOLOGICAL MANAGEMENT (NUTRITIONAL AND COLORING) MEDIATED CONTROL OF RED PALM WEEVIL (*RHYNCHOPHORUS FERRUGINEUS*)

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Abstract. Despite the severe relevance of Red Palm Weevil (RPW) *Rhynchophorus ferrugineus* as an insect pest, the strategies applied to control it were poorly sufficient. Hence, this study tested the effects of using food bait pheromone traps (FBPTs) to control RPW. In this context, the experimental design used three types of baits (banana, date, and mixture) represented as (300 g banana, 300 g date, and 300 g mixture "150 g banana & 150 g date); three colors (red; white and black) and their combinations. They were checked once every two weeks to collect the samples caught and evaluate the efficiency roles in controlling RPW regarding the dynamic fluctuation and seasonal activity of RPW during 2021 at Taif governorate, Saudi Arabia. Data illuminated that the black color was significantly ($P < 0.05$) higher in attracting RPW, followed by red, and the lowest value was recorded at white color with the same bait. Notably, black traps containing date had the highest significance ($P < 0.05$), and the lowest was recorded in white traps containing bananas in attracting RPW. According to the presence of RPW throughout the year, the highest and lowest population densities were recorded during April and September, respectively. Remarkably, results exhibited a negative significant correlation between RPW mean population density and temperature, but there was a positive correlation between seasonal abundance and relative humidity. Interestingly, this study remarkably the pheromone traps with baits partially with data showed a significant effect in controlling RPW. Data showed that the dynamic fluctuation relationship of the red palm weevil and its relationship to some environmental factors have been changed during different seasons and peaks of weevil activity during spring and lowest during autumn.
Keywords: *control strategies, data palm, red palm weevil, weather fluctuation*

Introduction

The date palm, or *Phoenix dactylifera* L., is the most widely grown plant in arid and semi-arid environments, and it is one of the oldest fruit trees in cultivation worldwide as well as socioeconomic relevance (Al-Shwyeh, 2019). Numerous insects prey on date palms, inflicting serious infections and negatively impacting the production and quality of dates. The most significant of these insects is the red palm weevil, *Rhynchophorus ferrugineus* (RPW), which damages date palms and causes economic losses (Manee et al., 2023). It was first discovered in the Gulf region in the late 20th century, severely damaging palm trees; later, it began to spread, significantly impacting other locations (El-Shafie and Faleiro, 2020; Al-Otaibi et al., 2022). However, finding sustainable ways to stop the spread of RPW is imperative, as the annual cost of controlling it on palm farms in Saudi Arabia alone surpasses 8 million USD (Manee et al., 2023).

For many years, conventional pest management techniques, such as chemical pesticides, have been used to control insect pests that attack food crops (Soomro et al., 2022). However, the substances in pesticides can harm human health, have unintended effects on other species, including the pest's natural enemies, harm the environment, and occasionally cause further infestations after they are applied (Chaya, 2017). However, in Saudi Arabia, approximately 3,700 tons of pesticides are used annually, which have proven effective in controlling red palm weevil (Hajjar et al., 2021). The dangers of

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chemical pesticide use have prompted governments to switch to safer, more environmentally friendly methods of managing pests (Mohammed et al., 2020).

Growers worldwide urgently need an early detection and monitoring system for RPW because it is regarded as a critical component of its management Manee et al. (2023). Consequently, numerous techniques have been employed to identify *R. ferrugineus* in palm plantations, such as visual examinations, acoustic sensors (Potamitis et al., 2009, Mankin, 2011), sniffer dogs (Nakash et al., 2000), and pheromone traps (Faleiro and Ashok Kumar, 2008). All of these approaches, despite their apparent effectiveness, have some unique problems with implementation and logistics. However, after aggregation pheromone was identified and synthesized, RPW males released ferrugineol to draw in adults (Hallett et al., 1993). Also, Soomro et al. (2022) state that it is now a crucial part of the integrated management of RPW in practically all palm-growing regions of the world, either by itself or in conjunction with food baits. According to Mohamed Abuaglala and Al-Deeb (2012), there is a better way to manage the drop in the *R. ferrugineus* population than using a black pheromone trap filled with 100 g of dates or a pheromone trap filled with bananas and dates, respectively. Furthermore, effective knowledge of the tools used for population monitoring, identifying insect infestations before they cause economic harm, and determining when RPW peaks are essential components of insect pest control strategies (Manzoor et al., 2020).

This baseline data will assist us in developing a benchmark that subject-matter experts in the field can use for effective and efficient RPW management. Hence, the study's goals were to assess the effectiveness of pheromone traps in the case of bait and color on RPW attractiveness, as well as to ascertain the connections between RPW populations and weather, and to track the RPWs' seasonal activities.

Materials and Methods

Study area

The Taif Governorate's date palm farms served as the experimental site (24º 19' N, 50º 40' E), Kingdom of Saudi Arabia (KSA) in 2021 was conducted. Two factors were considered when choosing plantations: the same tree category and stopping all pest control operations in the data palm during the study (*Fig. 1*).

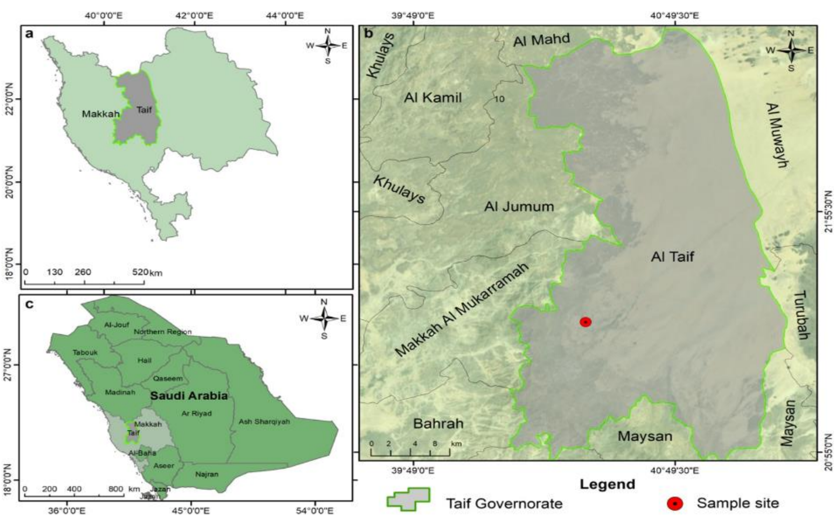

Figure 1. *Map showing the location of the study area*

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Trail procedure

Different colored traps (red, black, and white), were represented as well as 10 openings (6 in buckets and 4 in cover of buckets), and the outer part was covered with burlap. The traps were distributed randomly according to Mohammed et al. (2021). The iron wire secured the red palm weevil aggregation pheromone to the lid's lower surface. Two liters of water were set at its base to ensure that drawn weevils would never escape their trap. Every two weeks, the baits, and pheromone were changed with added water. Following the placement of the traps, observations were made once every two weeks to count and gather the number of RPW drawn to each treatment. Based on the unique characteristics described in the literature, the gathered adult weevils were further divided into males and females. In this study, the attraction of red palm weevil to three food baits represented as 300 g banana, 300 g date, and 300 g mixture "150 g banana & 150 g date), three colors (red, white& black) for traps (four replicates/ treatment), was tested (*Fig. 2*). The Taif Governorate's local meteorological station provided information on the temperature and humidity.

Figure 2. *Photomicrograph cultivated date palm and different baits used in the study*

Statistical analysis

The statistical analysis was conducted using IBM's (Chicago, Illinois, USA) SPSS 25.0 (Statistical Package for the Social Sciences). The data point was displayed as Mean ±SE. The Data had a normal distribution according to the Shapiro-Wilk and Kolmogorov-Smirnov tests. Levene's test established the homogeneity. The effect of baits, colors, and traps was assessed using one-way ANOVA on the data ($P < 0.05$), and Duncan's test, a post hoc test, was used to compare the various treatment levels at ($P < 0.05$). GraphPad Prism 8.0.02 was used to fit the correlation coefficient (r) and regression analysis to match the correlations between the parameters under study and treatment levels.

Results

The results (*Fig. 3*) showed that the highest overall attractiveness ($P < 0.05$) of *Rhynchophorus ferrugineu* of different colors at black, followed by red and white color, particularly in females than male groups. According to the regression fitting curve, the current study recommends using the data to attract the red palm weevil (*Fig. 4*).

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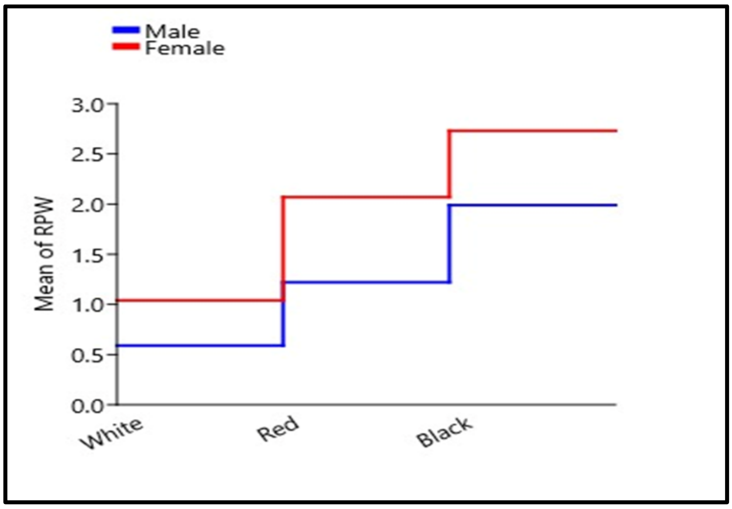

Figure 3. *Comparative overall attractiveness of RPW of different colors at the date palm growing areas of the study area. Data were represented as means ± SEM*

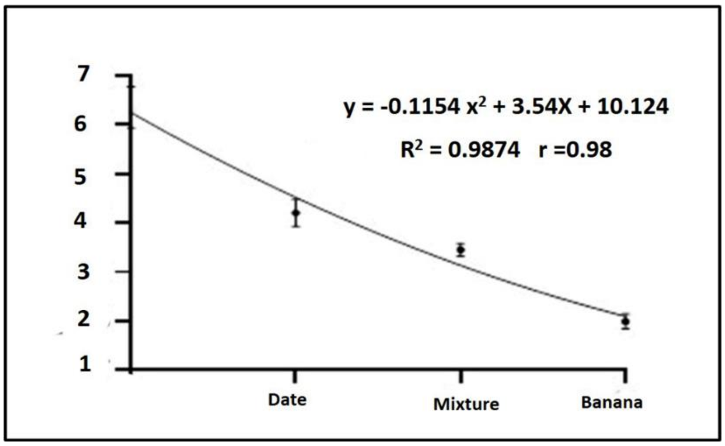

Figure 4. *Significant quadratic relationships and polynomial regression analysis (P < 0.05) between the attractiveness of RPW and different baits. Values expressed as means ±SE*

Data in *Fig. 5* observed that the trap black color with data appears to be the highest significantly than red and white color with the same bits and other groups. The banana bait with white color was the least attractive to the red palm weevil compared to the other group. Notably, the stunning rate of the red palm weevil was significantly greater in the female groups compared to the male group of PPW exposed to different bites and colors (P < 0.05).

The overall mean RPW captures over the several seasons are shown in *Fig. 6*, where there was a highly significant difference (P < 0.005) in the mean number of weevils captured during the spring season partially at females than males, and the lowest value was recorded during autumn. Moreover, there is a significant inversely relationship between temperature and the average number of RPW during the period of study (*Fig. 7*).

Table 1 shows that the highest numerical density of RPW in the study area (14.75±1.35) was recorded during April and the lowest value (1.33 ±0.39) during September. However, the minimum values of Humidity were recorded during August and

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June and the maximum during January and December. Conversely, the maximum values of temperature (43.3+0.66) were recorded during August, and the minimum value (29.0+0.57) during January.

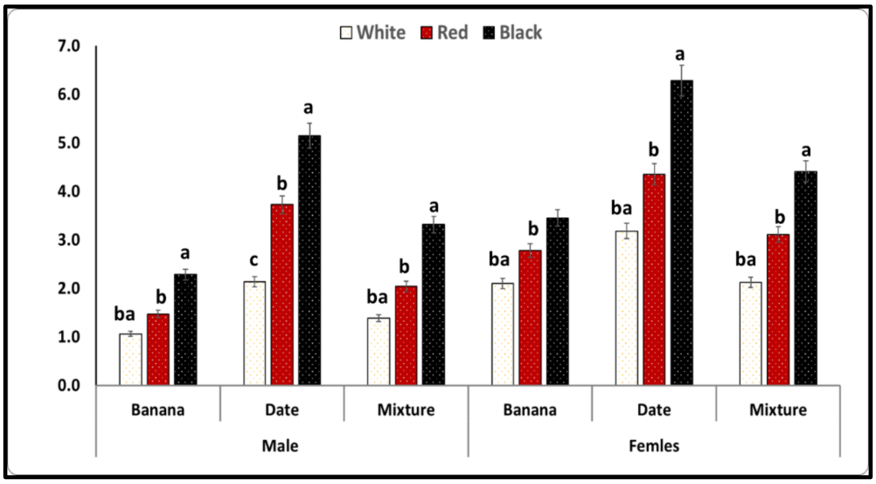

Figure 5. *Comparative overall attractiveness of RPW of different trap colors and food baits at the date palm growing of the study area. Data were represented as means ± SEM. Bars bearing different superscripts (Duncan's test) were significantly different (P ≤ 0.05)*

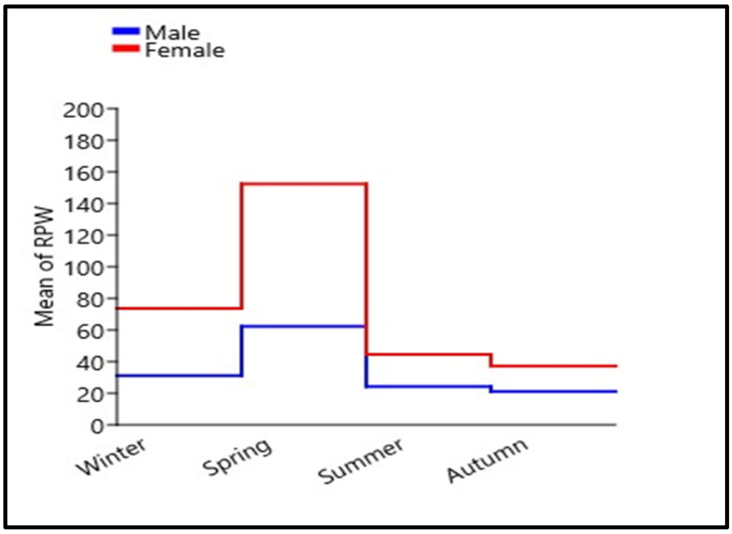

Figure 6. *Overall mean population of the red palm weevil insects in Taif City during different seasons. Data were represented as means ± SEM*

The Pearson correlation coefficients between the activity of red palm weevil, temperature, humidity, and different seasons are shown in *Table 2*. There was a significant negative correlation between the activity of red palm weevil and temperature during spring followed by summer partially in the female group. There were no significant variations between the winter and autumn seasons (P > 0.05). Conversely, the humidity showed a relative correlation with the activity of red palm weevil partially during the spring season in the female group, followed by summer, and the lowest value recorded during autumn.

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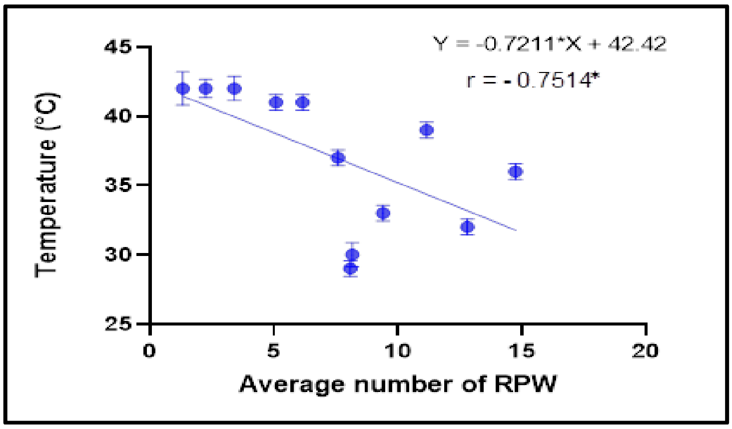

Figure 7. *Significant linear regression analysis (P < 0.05) between temperature and Average number of RPW. Values expressed as means ±SEM. r: Spearman correlation coefficient, * indicates a significant difference (P<0.05)*

Table 1. *Monthly average of red palm weevil insects in Taif City during 2021*

Month	Total attraction of RPW	Humidity	Temperature
Jan	8.08 ±1.33 ^{CDE}	57.0+3.04 ^{A}	29.0+0.57 ^{G}
Feb	8.16 ±0.87 ^{CDE}	54.0+2.30 ^{A}	30.6+0.88 ^{GF}
Mar	12.83±1.77 ^{AB}	46.0+1.15 ^{BC}	32.0+0.57 ^{EF}
Apr	14.75±1.35 ^{A}	42.0+1.14 ^{CD}	36.0+0.57 ^{D}
May	11.16±1.31 ^{BC}	34.0+2.30 ^{EFG}	39.0+0.57 ^{BC}
Jun	6.16 ±1.34 ^{DEF}	32.0+1.15 ^{G}	41.0+0.57 ^{AB}
Jul	5.08 ±0.65 ^{EFG}	33.0+1.15 ^{FG}	41.0+0.57 ^{AB}
Aug	4.25 ±0.76 ^{GH}	31.0+1.12 ^{G}	43.3+0.66 ^{A}
Sep	1.33 ±0.39 ^{H}	38.0+1.15 ^{DEF}	42.3+1.20 ^{A}
Oct	3.41 ±0.80 ^{FGH}	39.0+1.19 ^{DE}	40.0+0.88 ^{A}
Nov	7.58 ±1.52 ^{ED}	48.0+1.32 ^{B}	37.0+0.57 ^{CD}
Dec	9.41 ±1.65 ^{BCD}	56.0+3.46 ^{A}	33.0+0.57 ^{E}
LSD	3.42	5.93	2.082
P	*P < 0.05	*P < 0.05	*P < 0.05

Data were represented as a mean ± SEM. A one-way ANOVA test showed only a significant effect (*P < 0.05) by the asterisk symbol. The different superscript letters indicated that averages with these superscripts significantly (P<0.05) differ when compared in the same column according to the Duncan post-hock test

Table 2. *Pearson correlation coefficients between temperature, humidity, and male and female RPW activity*

Pearson correlation coefficients					
Activity of red palm weevil		**Spring**	**Summer**	**Autumn**	**winter**
Males	Temperature	- 0.81*	-0.58*	-0.46	-0.28
	Humidity	0.48	0.42	0.36	0.33
Females	Temperature	- 0.91*	-0.59*	-0.49	-0.35
	Humidity	0.50	0.45	0.40	0.37

* Correlation is significant at the 0.05 level (2-tailed)

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Discussion

The primary harmful insect pest of a wide variety of palm plants is the Red Palm Weevil (RPW) (Manee et al., 2023). Pheromone-baited traps, on the other hand, are essential to the integrated management of red palm weevil pests (Soomro et al., 2022). Therefore, this study aimed to ascertain the ideal color for the trap and the bait to use to capture the red palm weevils possible in the field in the Kingdom of Saudi Arabia.

The effectiveness *of Rhynchophorus ferrugineu* pheromone traps is influenced by trap color (Al-Saoud, 2010). The study found that black was the most alluring hue for luring adult *R. ferrugineus* than other traps. These increased capture rates suggest that the effectiveness of trapping might be nearly doubled by employing black traps (Mohamed Abuaglala and Al-Deeb, 2012). It is a significant improvement in trapping that will hopefully result in a large decrease in the population size of this major pest in KSA from the perspective of insect management (Al-Saoud, 2013). Attractively, the mixture of data bita and black color showed a significant increase in the attractiveness of RPW to other combined treatments. It may be due to fermented dates emitting volatile chemicals that attract adults of *R. ferrugineus* along with chromameter black color, which has low L-values (Faleiro, 2005; Mohamed Abuaglala and Al-Deeb, 2012; Soomro et al., 2022). Additionally, adding fermenting plant materials to pheromone traps increases the attraction of red palm weevils (Oehlschlager, 2016; Junejo et al., 2021), consistent with our result assay findings Mohamed Abuaglala and Al-Deeb (2012) found that black had the lowest L-value and was the darkest hue in the current investigation. These findings suggest that trap surfaces with lower L-values must be investigated in subsequent research to see whether they might enhance trap attraction even more (Junejo et al., 2021). Correspondingly, demonstrated that employing date bait traps were sufficient to outperform other groups in trapping efficacy; this could be because dates release volatile compounds that attract adult *R. ferrugineus* (Abbas et al., 2019). Additionally, the colors with low L-values are perhaps what attracted adult *R. ferrugineus*, based on the chromameter color values (Oehlschlager, 2016). Hence, we can conclude the synergetic effect of bita and colour-promoting attract adults of *R. ferrugineus*.

In this study, the spring had a comparatively higher population of RPW than the other seasons; it's in line with Al-Saoud and Ajlan (2013), who noted the increasing population of RPW in date palms from March to April 2011, provided some support for the conclusions of this study. By comparison, September saw significantly lower population counts. Manzoor et al. (2020) found that weevil peak numbers from April to June showed a positive correlation with the average mean temperature across several study locations. The population distribution of RPW from several date palm locations in Pakistan was investigated, and these results were obtained.

Furthermore, more host volatile chemical secretions from the suckers that tend to draw the most significant number of weevils could be the cause of this variance in the population difference of RPW. Weevils also discovered that the soft-cut palm sections were more suitable for laying their eggs than the harder ones accessible throughout the pre-and post-sucker planting seasons (Soomro et al., 2022). In parallel, pheromone traps attracted and caught a comparatively more significant number of females than males. More basioconic sensillae are known to be present on the antennae of female RPWs than males., which may account for the increased capture rate of females compared to males in pheromone traps (Al-Saoud, 2010; Maruthadurai and Ramesh, 2020).

The current study found that climatic parameters, such as temperatures, relative humidity, and RPW attraction, substantially impacted the effectiveness of pheromone

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traps in attracting weevils and, consequently, on weevil population fluctuations. Relative humidity had a slight but beneficial effect on the weevil population in the spring, according to correlation analysis. Although they played a positive function in the spring, fluctuation temperatures also demonstrated a relatively negative effect on the population fluctuation of RPW than relative humidity. Additionally, the correlation model verified that temperature and relative humidity had a positive and negative effect on the ability of pheromone traps to draw in adult RPW for this investigation. This study indicated that temperature and relative humidity substantially impacted the growth and development of the red palm weevil, playing negative and positive functions, respectively. Huang et al. (2008). Also, because they gathered fewer weevils during periods of high rainfall and low temperatures (Al-Deeb and Khalaf, 2015) discovered a substantial impact of climatic conditions on the ability of aggregation pheromones to attract in and control RPW. But since environmental factors can have a positive or negative effect on any living thing's activities, our study and the numerous studies mentioned above also supported the idea that temperature and relative humidity are essential weather parameters that influence RPW population fluctuations by affecting the ability of aggregation pheromones to attract them.

Conclusion

In summary, better control outcomes and a possible reduction in the *R. ferrugineus* population over time can be achieved by using a black pheromone trap with bait partially, dates. Because it is an environmentally friendly control method that doesn't produce chemical pollution or promote insecticide resistance, this trap is a great tool for managing *R. ferrugineus*. Thus, in light of the study's findings, it is advised that mass RPW trapping and ongoing monitoring be done in notable growth regions, especially in the spring, to stop the spread of the disease and lessen its losses in already-existing orchards.

Declaration of competing interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement. Data will be made available on request.

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