

Spatiotemporal Distribution and Bioassay Management Techniques against Red Palm Weevil, *Rhynchophorus ferrugineus* (Olivier, 1790) in Khairpur, Sindh, Pakistan

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ABSTRACT

Date palm, *Phoenix dactylifera* L., has a long history, and grows well in tropical and sub-tropical regions. In Pakistan, Khairpur, Sindh is a conspicuous and robust zone for date cultivation but massively harmed by red palm weevils (*Rhynchophorus ferrugineus*). Date is considered as significant eatable fruit, complete diet and supporting high crop yields. This study was carried out under field and laboratory conditions during two consequent years, 2022 and 2023. In both years, the overall peak damage percentage was recorded 26.13±1.92 and 17.39±1.71 on Aseel variety at Shadi Shaheed, followed by 21.77±1.83 and 15.45±1.62 in Union Council Mohail, and 18.32±1.76 and 14.15±1.55 in Pir-jo-Goth. Whereas; minimum damage percentage was recorded as 14.46±1.46 and 9.65±1.44 at Date Palm Research Institute. The highest infestation % of red palm weevil (RPW) was recorded at 5 ft, followed by the middle portion at 8 ft and the top portion at 10 ft of date palm orchards during 2022-23. The maximum trunk infestation was recorded (14.96±1.43 and 11.03±1.35 %) at Shadi Shaheed compared to Union Council Mohail (11.09±1.25 and 8.33±1.21), Pir-jo-Goth (11.55±1.38 and 8.97±1.26 %) and DPRI (9.02±1.31 and 5.85±1.22 %) at filed conditions. The mortality percentage was recorded on 2nd, 3rd and 4th day of post-treatment period in both years. The overall high mortality during 2022 and 2023 was caused by Fipronil (53.39±1.95 and 49.35±1.78), followed by Spinosad (51.89±1.82 and 44.36±1.65), Profenofos (48.83±1.68 and 44.12±1.58) and Imidacloprid (40.05±1.44 and 35.47±1.26) against the larval population of *Rhynchophorus ferrugineus* under laboratory conditions.

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Authors' Contribution

YB is the principal author, who prepared and applied insecticides at different heights of the host trees, collected pest population data, recorded mortality % and calculated efficacy of each insecticide. WMM conceptualization, software, and manuscript write-up. HAS Supervised during the whole research study period, and data analysis, visualization. SAU helped proofreading and final editing. SAK participated in validation, methodology, conceived, designated and tool arrangement. SS helped for pest data collection, and data creation.

Key words

Aseel variety, Date palm, Insecticides, Fipronil, Mortality%, Red palm weevil

INTRODUCTION

Date palm (*Phoenix dactylifera* L.), symbol of culture, known as a “tree of life”, the dioecious world’s oldest domesticated plant, has been cultivated 5000 years ago in Mesopotamia (Fernandez-Lopez *et al.*, 2022). This fruit contains antioxidants, water- and fat-soluble vitamins, bioactive phytochemicals, minerals and polysaccharides (Al-Mssallem *et al.*, 2019). Pakistan is the core region for date production which serves as a pivotal

role in the economic heritage and the country holds 5th position in the world (Jatoi *et al.*, 2021). The date palm is an important cash crop of Sindh (Mallah *et al.*, 2017), which is ideal for cultivation of many novel palm varieties due to favorable climatic conditions (Sahito *et al.*, 2017). The fruit of these cultivars is rich in essential nutrients, but Aseel cultivar is regarded as the “Queen” and the most successful commercial variety for the local people of Khairpur, Sindh (Sahito *et al.*, 2017). Unfortunately, the production of date fruit is decreasing due to the adverse effects of abiotic and biotic factors, prolonged drought, diseases and salinity but insect pests are the key factors that cause serious threat and maximum yield losses to date palm production (Sedra, 2015).

Red palm weevil, *Rhynchophorus ferrugineus* (Olivier, 1790) (Coleoptera: Curculionidae) is a major and potential insect pest of dates, the most devastating indigenous and notorious species from Southeast Asia (Najim *et al.*, 2024). Unfortunately, during the last three decades it has become the most dangerous around the globe due to the movement

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of infested palms in different geographical regions (Rasool *et al.*, 2024). The flood water systems, expanding soil wetness and people moving through swarming branch-offs are reasonable circumstances for the spreading of this tissue-boring insect pest species, which massively harms tree trunks (Kubar *et al.*, 2017). The larvae of this species have a cryptic behaviour, burrow into the palms of the trunk, feed tissue constituents, causing discoloration, wilting, eventually leading to death and causing incredible financial problems (Meridja *et al.*, 2020). *R. ferrugineus* is sporadic in feeding habits and habitats, growth of larvae, body weight, reproduction, morphology and other life patterns, primarily depending on the quality of palm tissues (Mangrio *et al.*, 2024). The larvae stages of insect pests are voracious feeders but can be managed through integrated pest management strategies (Mangrio *et al.*, 2020). The life expectancy of these pest insects can be influenced by the fluctuations of environmental temperature (Mastoi *et al.*, 2023). Including the red palm weevil (RPW), the population of the saw-toothed grain beetle (Kousar *et al.*, 2020) and lesser date moth extremely harming *P. dactylifera* causing tremendous economic losses in the study area (Jatoi *et al.*, 2020). It is needed to know about population fluctuations of RPW as to take early precautionary measures and eco-friendly IPM control strategies against this pest species. The aim of this study was to investigate the spatiotemporal distribution of the RPW (*Rhynchophorus ferrugineus*) and to evaluate the effectiveness of different bioassay-based management techniques for its control in date palm orchards of Khairpur, Sindh, Pakistan.

MATERIALS AND METHODS

Study area

The district Khairpur, is the 2nd largest in Sindh, situated at 27.529951°N, 68.758141°E. It is regarded as the richest zone, biodiversity center, and home ground for variety of date palm cultivars. The fruit of date palms is the profitable, exportable, and main source of livelihood of the local people of this region. The pest infestation data was gathered from four palm gardens namely Shahdi Shaheed, Pir-jo-Goth, Mohail UC, and Date Palm Research Institute.

RPW damage on Aseel date palm variety

Aseel, the most commercial and novel variety of this region was selected to examine the damage done by RPW during 2022-23 in 8 acres of date palm tree orchard, where spatiotemporal distribution of RPW, was checked on monthly basis from four different study locations, Shadi Shaheed (T1), Mohail UC (T2), Pir-jo-Goth (T3), and DPRI (T4) of district, Khairpur-Sindh. For this purpose, the 50 date palm trees out of 552 trees were randomly

selected monthly. The infected trees were marked with red ribbon to avoid re-sampling.

The infestation (%) was recorded every month during each year at 5ft, 8ft, and 10ft height. The most infected date palm trees were marked by a white colored cloth ribbon for its proper promulgation of pest appearance throughout the trunks. Habitually, the pest attacks occur when the suckers are transplanted from the mother plant. First, the pest bores from the root side move to the upper side for its nutritional need. The completion of larval stages, and pupation happen in the middle part, smoothly reaches the upper part of the trunk through its inner fibrous veins as a food eating purpose. The outer layer of the RPW bores outside or interacts inside the trunk and causes severe damage. For this purpose, the date palm tree orchards were kept under observation, and the infestation percentage was determined as future control strategies may be initiated. The different trunk positions were evaluated to determine the damage of RPW and attacked spots were assessed using measuring tape.

Bio-assay of different insecticides against RPW

Four different synthetic insecticides: Fipronil (Bayer, Germany), Spinosad (Arys ta life Science, Japan), Profenofos (Syngenta, USA), and Imidacloprid (Bayer, Germany) were applied per recommended doses (Table I). The insects culture was maintained in plastic jars in Department of Zoology, Shah Abdul Latif University. The eggs and different stages of larvae collected from the highly infested Aseel date palm variety from the study points in the district Khairpur were kept over the fresh food in the Entomology Laboratory with photoperiod of 12L: 12D h (Light: Darkness). The bulk culture was maintained at 25±2°C and 65-70 RH% as reported by Mal *et al.* (2024).

Table I. The insecticides with their identification and proper prescribed doses for bioassay.

S. No	Common name (brand name)	Formula-tion	Dose	
			Per acre	Per L
1	Fipronil (Regent)	5% SC	500ml	5 ml
2	Spinosad (Tracer)	20 SC	200ml	2 ml
3	Profenofos (Curacron)	50 EC	500ml	2.5 ml
4	Imidacloprid (Confidor)	20 SL	200ml	5 ml

Preparation of bio-assay foodstuff

The food material (3 × 6 inches) in size was collected from 3-year-old suckers of the Aseel date palm variety growing in orchards with 15-years old mother plants.

This foodstuff is cut in to the small pieces at (3 x 1") as a fresh food for the larval stages of RPW without use of insecticide. Whilst the insecticide dilution was made in 1 liter of water in a scientific glass beaker, and for absorption foodstuff was dipped and left for 2 min. For insecticide treatment the food was soaked in insecticide dulcin (in one liter of water) for 5 min in normal room temperature and kept on Whitman® filter paper to dry. The laid eggs of RPW were kept on fresh foodstuff over blotting paper in 12 cm diameter of Petri-dishes until hatching of larvae. Thereafter, larvae hatched over the date palm Aseel variety and food was given to prolong their life cycle. At the 2nd, 3rd and 4th voracious feeding stages, they were preferably released over diluted foodstuff as for bioassay dip method. Each treatment consisted of over 50 larvae and was replicated 5 times.

Bioassay method under laboratory conditions and data collection

The data on spatiotemporal distribution was taken on monthly basis throughout the two consecutive years, 2022-23. A total of four treatments and control were used: Fipronil 5 ml per liter, Spinosad 2 ml per liter, Profenofos 2.5 ml per liter, and Imidacloprid 5 ml per liter. In each treatment, 50 larvae of the RPW were kept examining the efficacy of the tested insecticides. The data was taken on 2nd, 3rd and 5th post-treatment days, and the mortality percentage was evaluated through Abbot Formula. The larval stage of insects was considered dead when it neither moved nor responded to the use of camel hairbrush.

Statistical analysis

The pest data was statistically analyzed to check its spatiotemporal monthly damage, infestation, trunk % infestation throughout year. The same study was repeated for the second year thereafter, both years data was depicted as overall mean with standard deviations. The damage was calculated for 50 out of a total of 552 date palm trees, and the overall damage percentage was determined through ANOVA. The data was subjected to analysis of variance year wise and then overall mean data was separately analyzed to check its significant difference and % damage was calculated at $P < 0.05$. The infestation level on the trunk was considered at 5th, 8th, and 10th ft. The efficacy of all insecticides was determined for all replications and results are shown as Mean % mortality $\pm$ standard deviations. The comparison of different insecticides was done through analysis of variance at 95% confidence level. The data of date palm damage and infestation were analysed through SWX, 8.1 software and with the help of Origin 2017, 64 Bit software figures were formulated.

RESULTS

Damage done by RPW on Aseel date palm variety

The peak percentage damage in 2022 was recorded during July and August (36.23 ± 3.67) at Shadi Shaheed, compared to Mohail UC (28.25 ± 3.34), Pir-jo-Goth (24.56 ± 2.87) and DPRI (21.24 ± 1.58) locations. During June and July, pest infestation was high at Shadi Shaheed (28.22 ± 3.55), Mohail UC (23.45 ± 2.88), Pir-jo-Goth (19.77 ± 2.37) and DPRI (14.22 ± 1.56). It was high at Shadi Shaheed (25.08 ± 1.56) during September and October, compared to Mohail UC (22.32 ± 2.87), Pir-jo-goth (17.55 ± 1.72), and DPRI (14.46 ± 2.22) (Fig. 1A). In March and April, the pest damage was high in Shadi Shaheed (24.06 ± 2.35), compared to Mohail UC (21.34 ± 2.42), Pir-jo-Goth (16.22 ± 1.75), and DPRI (13.45 ± 1.35) palm garden. The pest in November and December was recorded at Shadi Shaheed (21.08 ± 1.25) locality, Mohail UC (18.22 ± 2.65), Pir-jo-Goth (17.78 ± 1.55), and DPRI (12.38 ± 1.28). On the other hand the minimum RPW damage was recorded at Shadi Shaheed (22.08 ± 2.23), followed by Mohail UC (17.05 ± 2.32), Pir-jo-Goth (14.02 ± 2.28), and DPRI (11.02 ± 1.28) in January and February. Statistical analysis showed significant differences were found after four treatments among all pair wise comparison test ($DF = 3$; $F = 34.76$; $P = 0.01$) whereas in the different months of the year the damage % was calculated as depicted in Figure 1A ($DF = 11$; $F = 77.26$; $P = 0.03$) at ($P < 0.05$).

The data collected for 2023 demonstrated the maximum spatiotemporal damage percent of RPW was recorded in July and August at Shadi Shaheed (22.05 ± 3.51) followed by Mohail UC (19.33 ± 3.19), Pir-jo-Goth (17.66 ± 2.76), and DPRI (11.55 ± 1.44). In May and June, the % damage was at Shadi Shaheed (21.01 ± 3.51), Mohail UC (18.39 ± 2.56), Pir-jo-Goth (15.66 ± 1.65), and DPRI (10.13 ± 1.38) locations. In September and October it was, at Shadi Shaheed (16.02 ± 1.71), Mohail UC (15.27 ± 2.82), Pir-jo-Goth (14.36 ± 1.63), and DPRI (10.37 ± 2.16). In March and April the % damage was at Shadi Shaheed (16.04 ± 2.38), Mohail UC (14.42 ± 2.32), Pir-jo-Goth (13.11 ± 1.82), and DPRI (9.31 ± 1.12). In November and December the damage was at Shadi Shaheed (14.13 ± 1.51), Mohail UC (13.17 ± 2.81), Pir-jo-Goth (13.03 ± 1.45), and DPRI (8.51 ± 1.36). However, the minimum damage percentage was calculated in January and February at Shadi Shaheed (15.06 ± 2.19), Mohail UC (12.11 ± 2.26), Pir-jo-Goth (11.07 ± 2.21), and DPRI (8.01 ± 1.22), respectively. In all months of the year, the population fluctuation of the pest was recorded at its peak level with the maximum damage percentage in July and August and minimum in January and February respectively, as shown in Figure 1B. Analysis of the variance of the pest data was recorded as

significant ($DF=3$; $F=18.90$; $P=0.02$) among the location, whereas it was found significant in different months of the year ($DF=11$; $F=18.90$; $P=0.04$). Statistically found with significant differences among the homogenous groups and damage % as observed at $P<0.05$ level.

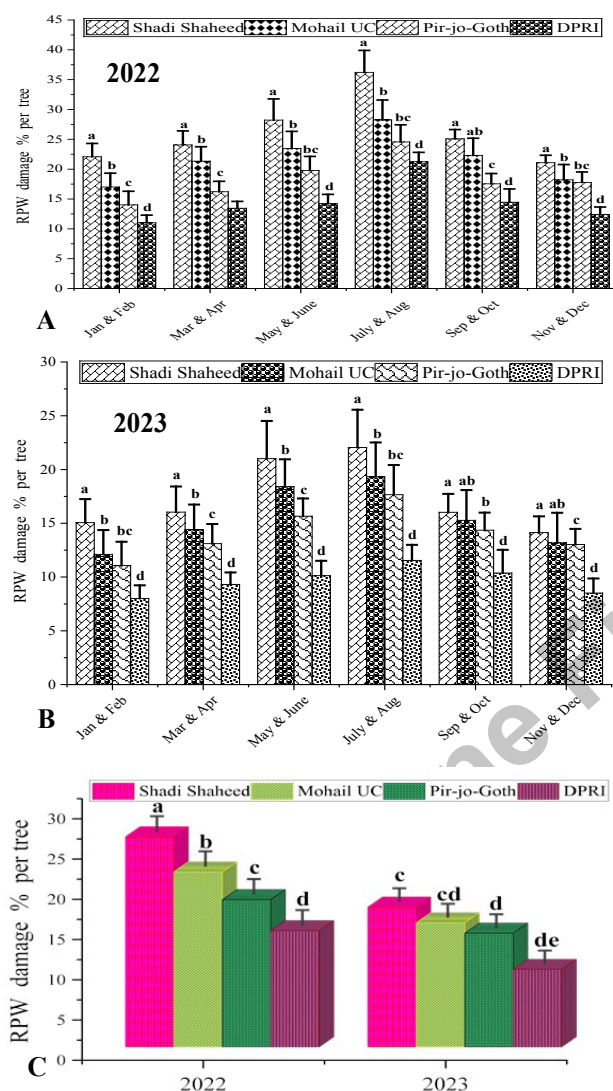


Fig. 1. The percentage damage of RPW on Aseel date palm variety in different months of 2022 (A), and 2023 (B). C represents overall spatiotemporal damage % of RPW on Aseel variety during, 2022-23.

Figure 1C shows the percentage damage of *R. ferrugineus* during both years of the study, but the maximum was recorded in July and August, followed by May and June, September and October, March and April, January and February, November and December, respectively. The overall maximum pest percent damage

was recorded at Shadi Shaheed (26.13 ± 1.92), followed by Mohail UC (21.77 ± 1.83), Pir-jo-Goth (18.32 ± 1.76), and DPRI (14.46 ± 1.46) in 1st year of the study. While, in 2nd year of the study period the overall RPW damage % was calculated at Shadi Shaheed (17.39 ± 1.71), Mohail UC (15.45 ± 1.62), Pir-jo-Goth (14.15 ± 1.55), and DPRI (9.65 ± 1.44) locations, respectively. During the study period, the maximum damage percent of RPW was reported in 2022 as compared to 2023. In fact, it is due to high rains in the study area as shown in Figure 1C. The analysis shows significant differences in both years of the study period ($DF=1$; $F=16.22$; $P=0.02$), whereas the LSD shows significant differences reported at ($P<0.05$) level ($DF=3$; $F=35.03$; $P=0.01$).

Spatiotemporal distribution of RPW on date palm trunk at different heights

During the study period in 2022, it was frequently observed that the pest caused infestation at distinct heights on the trunks of date palm trees at under given sites of the study area. The higher infestation % was reported at 5 ft when compared to the upper portions of the date palm trees. The peak infestation % was recorded (18.25 ± 1.55) upto 5 ft, compared to 8 ft (14.25 ± 1.68), and 10 ft (12.38 ± 1.21) at Shadi Shaheed date palm orchards. The infested spot on the trunk was observed with an overall mean infestation (12.32 ± 1.24) up to 5 ft followed by 8 ft (11.36 ± 1.28), and 10 ft (9.58 ± 0.95) at Mohail UC. The infestation % on trunk spots were documented up to 5 ft (16.58 ± 1.48), 8 ft (12.52 ± 1.88), and 10 ft (10.75 ± 1.76) heights at Pir-jo-Goth location. The minimum trunk spot infestation was calculated as 10.25 ± 1.11 at 5 ft height, 9.38 ± 0.98 at 8 ft, and 07.44 ± 0.78 up to 10 ft at DPRI. ANOVA of pest infestation % on trunk spot was found significant differences at four locations of research conducted studies ($DF=3$; $F=19.43$; $P=0.02$), hence at three different heights ($DF=2$; $F=21.88$; $P=0.01$) were calculated at ($P<0.05$). The most infested date palms were recorded at Shadi Shaheed when compared to other prescribed locations, as shown in Figure 2A.

Figure 2B shows the RPW trunk spots on Aseel palm during 2023. The early detection of infested palms is a bit critical to understand all life associated characteristics of this potential species to avoid the date palm death. The spots caused by the spatiotemporal distribution of RPW on trunks of date palm trees at different heights were observed, and the % infestation was calculated at given research conducted fields. The peak infestation was recorded at the 5 ft range as compared to 8 ft and 10 ft. The maximum degree of % infestation per spot was recorded up to 5 ft (13.71 ± 1.68), 8 ft (10.31 ± 1.31) and 10 ft (9.07 ± 1.06) at Shadi Shaheed

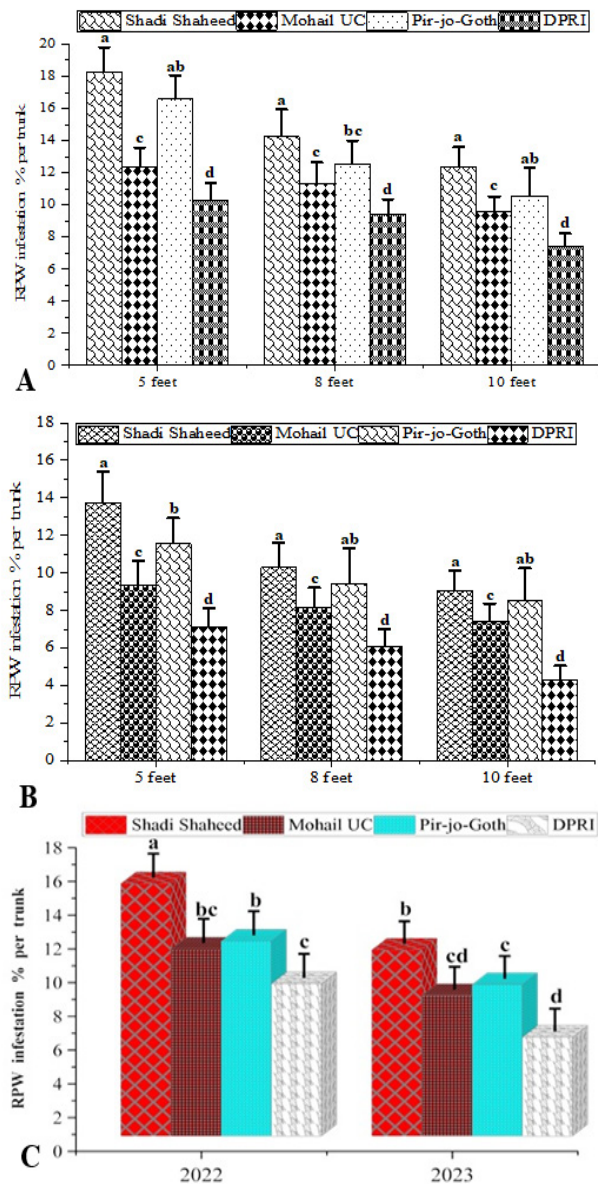


Fig. 2. Red palm weevil trunk spots infestation (%) on trunks of the Aseel variety during 2022 (A) and 2023 (B). C shows The overall mean population of RPW causing spots of trunks of the Aseel variety (2022-2023).

locations. The % infestation spot was calculated as 9.38 ± 1.28 at 5 ft, 8.18 ± 1.03 at 8 ft, 7.43 ± 0.94 at 10 ft Mohail UC location. Consequently, it was documented 11.56 ± 1.36 at 5 ft, 9.41 ± 1.93 at 8 ft, and 8.53 ± 1.74 at 10 ft at Pir-jo-Goth location. However, the minimum spot infestation % was recorded at 5 (7.12 ± 1.01), 8 (6.11 ± 0.93), and at 10 ft (4.33 ± 0.74) at DPRI. The degree of % infestation per spot at each location was found at different research conducted locations ($DF=3$; $F=19.24$; $P=0.03$), and at

different heights ($DF=2$; $F=31.45$; $P=0.04$) those found with significant difference when the LSD was carried out at ($P<0.05$). The maximum spots infestation formed by RPW were found at Shadi Shaheed location followed by Mohail UC, Pir-jo-Goth, and DPRI, respectively; further justification is given in Figure 2A.

Figure 2C shows the overall RPW trunk spot infestation on Aseel date variety at different heights, 2022-23. During the research study period, it was frequently observed that larvae spatiotemporal distribution of RPW caused infestation at different heights on the trunk of date palms. During 2022, the maximum trunk spot and infestation of the pest was recorded at Shadi Shaheed (14.96 ± 1.13), Pir-jo-Goth (11.55 ± 1.38), Mohail UC (11.09 ± 1.25), and DPRI (9.02 ± 1.31). During 2023, the maximum population on trunk spot was recorded at Shadi Shaheed (11.03 ± 1.35), Pir-jo-Goth (8.97 ± 1.26), Mohail UC (8.33 ± 1.21), and DPRI (5.85 ± 1.22). The overall maximum trunk spot infestation was recorded during 2022 as compared to 2023 at Shadi Shaheed, followed by Mohail UC, Pir-jo-Goth, and DPRI as depicted in Figure 2C. The ANOVA was done through RCBD, and significant differences were found in % infestation in different studies given locations ($DF=3$; $F=107.53$; $P=0.02$) and in both years ($DF=1$; $F=58.04$; $P=0.04$). The least significant difference was reported at $P<0.05$ level.

Effect of different insecticides on the population of RPW

Figure 3 shows the effect of different insecticides used for controlling the RPW infesting date palm. In 2022 four different insecticides, Fipronil, Spinosad, Profenofos, and Imidacloprid were applied under laboratory conditions through bioassay method to control the population of RPW. After application of fipronil, the data was recorded on 2nd day with mortality percent (38.22 ± 6.11), followed by 3rd day (52.66 ± 7.25), and 5th day (96.28 ± 8.33). The % mortality was calculated after 2nd day (33.66 ± 3.55), 3rd day (49.45 ± 3.47), and 5th day (66.57 ± 3.15) of the application of spinosad insecticide. The efficacy of profenofos was reported on 2nd day (35.55 ± 5.22) followed by 3rd day (47.65 ± 5.55) and 5th day, (63.28 ± 6.21) with % mortality as observed in post-treatment data collection. The imidacloprid was recorded on 2nd day (27.35 ± 2.75), 3rd day (42.52 ± 4.58) and 5th day (50.27 ± 4.55). When the % mortality of the pest was statistically analyzed, it was found to be statistically significant in the bioassay management method done through 4 different insecticides ($DF=3$; $F=119.72$; $P=0.01$) when compared with control treatment, and in different days found with significant difference at ($P<0.05$) level ($DF=2$; $F=14.08$; $P=0.03$), as shown in (Fig. 3A).

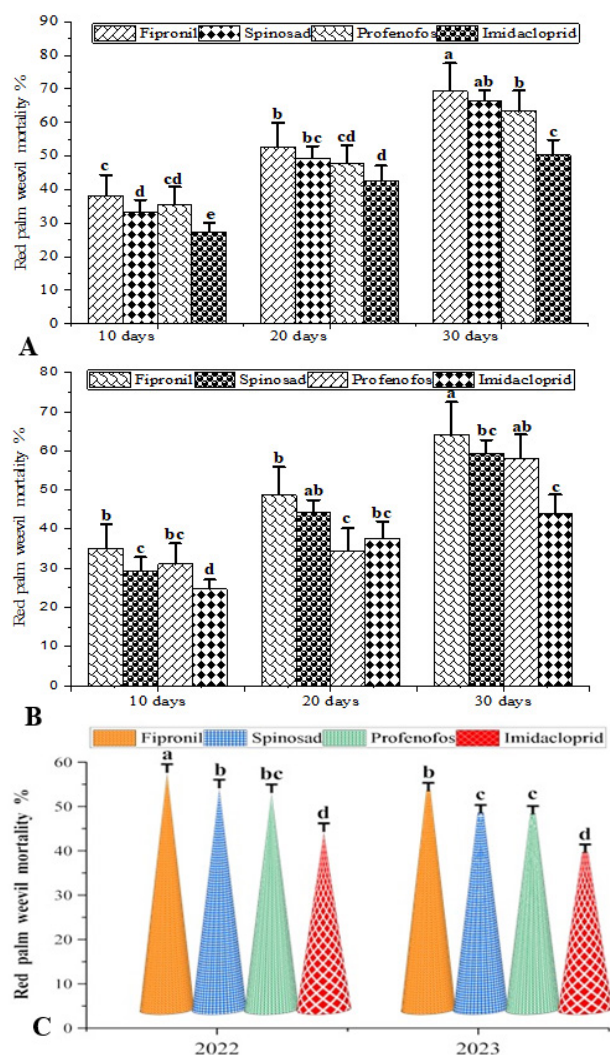


Fig. 3. The bioassay mortality % after the application of different insecticides, during 2022 (A) and 2023 (B). C shows overall bioassay mortality % of RPW with different insecticides during 2022-23.

The larvae of insect pests were kept under observation in 2023, as through the application of fipronil, profenofos, imidacloprid and spinosad insecticides were determined by efficacy level to check out the % mortality. The maximum mortality was recorded by the application of fipronil at 35.08 ± 6.16 after 2nd day, 48.74 ± 7.13 after 3rd day and 64.24 ± 8.22 after 5th day. The efficacy of the Spinosad was recorded at $29.35 \pm 3.46\%$ on 2nd day, 44.27 ± 3.18 on 3rd day, and 59.46 ± 7.11 on 5th day. The efficacy level of the profenofos was calculated at 31.03 ± 5.29 on 2nd day, 43.31 ± 5.91 on 3rd day, and 58.03 ± 6.14 on 5th day. While Imidacloprid displays efficacy at $24.68 \pm 2.39\%$ on 2nd day, 37.59 ± 4.39 3rd day, 44.13 ± 7.46 on 5th day, respectively.

All insecticides were found effective but fipronil proved to have maximum efficacy against RPW % mortality. As post-treatment, the maximum mortality percentage was calculated at 5th day followed by 3rd and 2nd day, respectively. When percent mortality was statistically analyzed and found with ($DF=3$; 97.00 ; $P=0.04$) significant difference after post-treatment among insecticides ($DF=2$; $F=13.86$; $P=0.04$) and within the days at was also found with significant differences in the % mortality when LSD was evaluated at $P<0.05$ level, as depicted in Figure 3B.

Figure 3C shows the overall pool data of the bioassay of different insecticides, 2022-23. During both years of the study, the RPW larvae populations were managed by the application of different recommended insecticides via bioassay method and toxicity of the insecticides were recorded. During the 1st year study, the maximum larvae mortality % was recorded by fipronil at 53.39 ± 1.95 followed by spinosad (49.89 ± 1.82), profenofos (48.83 ± 1.68), and imidacloprid (40.05 ± 1.44). In the 2nd year, again fipronil proved with more efficacy, that provided % mortality at 51.35 ± 1.78 followed by spinosad (44.36 ± 1.65), profenofos (44.12 ± 1.58), and imidacloprid (35.47 ± 1.26). All applied insecticides proved to control population but fipronil was found with maximum efficacy as compared to other insecticides and all the insecticides showed maximum mortality on the 5th day as compared to 3rd and 2nd days as justified in Figure 3C. The significant difference was observed in larvae % mortality at ($DF=3$; $F=234.40$; $P=0.02$) as post-treatment observation respectively, and among the years as conducted in two years of study plan ($DF=1$; $F=343.81$; $P=0.04$).

The main motive of this study was to evaluate the efficacy of four insecticides claimed to be effective against population reduction of RPW. Nevertheless, the proper use of chemical compounds as well as applications to monitor and control strategies still need to be explored. The findings of the present study can contribute to the development of effective Integrated Pest Management (IPM) strategies against the RPW. Such an integrated approach can enhance control efficiency, minimize economic losses, and reduce the excessive reliance on chemical insecticides as depicted in Figure 4.

DISCUSSION

Our findings exhibited the maximum % damage at Shadi Shaheed compared to other study locations. Whereas peak prevalence of larvae infestation was recorded May to August during both years. The maximum pest attacks were observed especially on spots of trunks in the date orchards at 5 ft range compared to 8 ft and 10 ft from all four study locations. This region delivers livelihood source

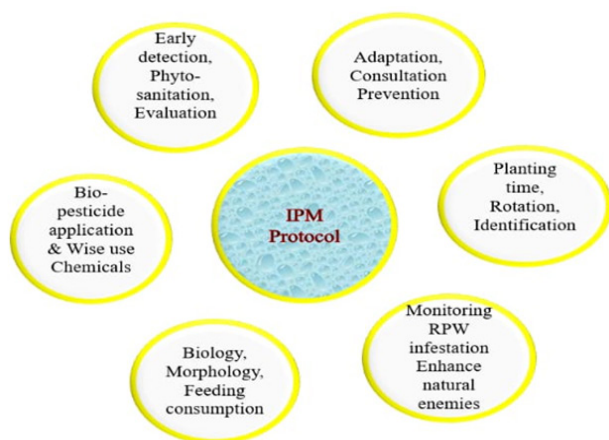


Fig. 4. Module of integrated pest management (IPM) strategies.

of numerous particularly backward areas families. The application of insecticides is considered crucial control and possible alternative measures to manage population of RPW under specific conditions. RPW acts as a major pest of palm plantation and it is impossible to detect pests earlier, only infestation later attack is conspicuous (Kharim *et al.*, 2022). Chemical control application is the common practice as preventive and curative measures to suppress the pest population. The application of organophosphate and carbamate insecticides is considered as the best approach against pest infestation. Among the tested treatments, fipronil demonstrated the highest efficacy in our study, which is in agreement with Al-Shawaf *et al.* (2013) who reported that the fipronil active ingredient through dipping of offshoot method resulted 100% RPW larval mortality after 30 min of application. Rasool *et al.* (2021) tested the toxicity of fipronil against the larval population of RPW and exhibited 100% mortality. The dimethoate, malathion, chlorpyrifos, fenitrothion, imidacloprid, cypermethrin, deltamethrin, beta-cyfluthrin, and carbaryl insecticides have proven effective against RPW (Rasool *et al.*, 2021). The agriculture department in Spain recommended thiamethoxam, chlorpyrifos, phosmet, and imidacloprid insecticides against the population reduction of RPW (Dembilio and Jaques, 2012). The deltamethrin proved to have potent toxic effect against this pest species (Shawir *et al.*, 2014). The insecticide, imidacloprid, proved most effective in population reduction of this pest (Soroker *et al.*, 2005).

According to the current control measures to deal with RPW, mainly are dependent on the application of certain chemicals, which have caused environmental contamination. Dembilio *et al.* (2015) through injection method, applied abamectin to the trunk and frond of

infested palms and proved up to 90% larval mortality of RPW. Meridja *et al.* (2020), through endotherapy method, found imidacloprid, emamectin benzoate and thiamethoxam to be the best control but emamectin was reported to be more systemic and persistent than others up to fifth month of the post-treatment. Mohammed *et al.* (2020), through dipping method applied fipronil and imidacloprid but fipronil calculated with more toxicity against larval population of RPW. Shar *et al.* (2012) applied methidathion, fipronil, and chlorpyrifos, which were found efficient but spirotetramat was recorded most effective against the RPW. The aluminium phosphide is considered as the quite sufficient and safe quarantine treatment against larvae stages of this species of weevil and can give complete control (Llacer *et al.*, 2010). Ferrugineol is the main accretion hormone of RPW in mass trapping applied in different parts of the world which are facing havoc with this pest species (Vacas *et al.*, 2014). The pheromone traps commonly catch adult at the ratio of two female and one male, and this strategy is the best tool to manage this potential pest before oviposition and infestations (Jayanth *et al.*, 2007). In different countries, attention has been given to controlling the population of RPW though biological control mechanisms (Mazza *et al.*, 2014). The introduction of black earwig, parasitic mites, entomopathogenic nematodes and fungi, family bacillaceae strains that have satisfactory control and are used as a preventive treatment against larvae of RPW (Francesca *et al.*, 2015).

However, the overreliance and unwise usage of various conventional insecticides can lead to developing resistance in RPW and ultimately increase the cost of chemical control. Alhewairini (2020) described that, through direct spray application, the larvae of this pest species show high susceptibility to acetamiprid and sulfoxaflor. Wakil *et al.* (2018) have shown that the RPW have high level of resistance capability against profenofos, phosphine, deltamethrin and cypermethrin. Therefore, new chemistry insecticides should be used wisely and carefully, and only effective and eco-friendly insecticides should be used against this insect pest species. Kousar *et al.* (2022) applied methyl bromide gas against STGB on dry and semi dry dates and proved with the population reduction but suggests that we should apply eco-friendly measures to secure date plantation and their dry and semi-dry fruit. Moreover, advanced IPM strategies should be adopted to reduce the application of toxic synthetic insecticides. The biopesticides and semiochemical techniques such as, “attract and kill”, “attract and infect”, “attract and sterilize”, “push and pull” are key eco-friendly factors to manage the population of weevils. The study given area is the richest fruitful zone and biodiversity

center for growing more than three hundred date palm varieties (Mangrio *et al.*, 2024). Develop new strategies and sustainable control measures with combination of neem oil and other commercial botanical insecticides to earn yield profitably (Mal *et al.*, 2024). The early detection, biological, semi-chemicals, chemical, phyto-sanitation, pruning, proper watering, weed eradication, cultural practices, antibiotic and antixenosis mechanisms are reliable and effective agronomic practices of IPM. In this study the fipronil exhibited the highest efficacy among the tested insecticides, it may be incorporated as a key chemical component of IPM programs.

CONCLUSION

The date palms at early-stage attack can be recovered by the application of insecticides or sanitation measures during suckers' removal from mother plants. It was frequently concluded that the damage and % infestation of the pest was reported from all study locations namely, Union Council Mohail, Pir-jo-Goth and DPRI, but Shaddi Shaheed location was found with maximum % damage as compared to other locations. For a two-year study plan, the infestation was recorded high in the months of May to August. This species has maximum trunk damage at the range of up to 5 ft distance compared to 8 ft and 10 ft. This study provides comparative evidence on the efficacy of four insecticides against red palm weevil but fipronil proved to be the best control followed by profenofos, spinosad and imidacloprid. Therefore, fipronil can be recommended as a promising tool in IPM strategies for red palm weevil management due to its maximum efficacy and potential to reduce pest populations effectively.

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This research study was approved by the Ethics

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Ethical statement

This study was conducted in accordance with the ethical standards and protocols approved by the Ethics Committee of Shah Abdul Latif University, Khairpur, Sindh, Pakistan.

Data availability statement

The data that supports the findings of this scientific documentary are available within the research paper.

Publication consent

For publishing this article all responsibilities are accepted by the corresponding author.

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The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

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The authors have declared no conflict of interest.

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