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Monitoring and control of red palm weevil infestation using IoT technology

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Abstract: Palms are slow-growing arboreal monocots predominantly distributed across warm regions and are frequently incorporated into parks, gardens, and roadsides. The red palm weevil, *Rhynchophorus ferrugineus*, is a highly destructive invasive insect that threatens palms. This field study investigated the effectiveness of a seismic sensor system to detect *R. ferrugineus* larvae on palm trees in the İzmir Metropolitan Municipality Culture Park. This park is home to a diverse collection of palm species, including *Washingtonia* sp. and *Phoenix dactylifera*. Seismic sensors were attached to the trunks of palm trees to detect the vibrations caused by feeding *R. ferrugineus* larvae and calibrated to distinguish between normal tree vibrations and those indicative of infestation. The number of clean, suspected, and infested trees was monitored regularly from 2023 to 2024. Results showed that the infestation rate of palm trees in the park area did not exceed 5%. A targeted control approach was adopted using Confidor SL 200 insecticide (Bayer Crop Science, Leverkusen, Germany), which was injected into the trunk. The efficacy of the insecticide during the surveillance period was 16–75%. This targeted control approach based on seismic detection can significantly reduce the use of insecticides and provide a more sustainable and environmentally friendly approach to palm tree protection.

Key words: *Rhynchophorus ferrugineus*, palm trees, seismic sensors, pest control

1. Introduction

The Arecaceae family (palms) encompass approximately 2600 species. This extensively cultivated group of slow-growing arboreal monocots are predominantly distributed across tropical, subtropical, and warm temperate regions. These perennial plants are characterized by their unique vertical stature (Eiserhardt et al., 2011; Muscarella et al., 2020). They are frequently incorporated into parks, gardens, and roadsides, particularly in coastal regions globally, including Türkiye. Furthermore, palms have a variety of growth forms, ranging from small shrubs to lianas and large trees (Kissling et al., 2019). They are iconic symbols often used in landscaping and tourism, contributing to their global popularity (Eiserhardt et al., 2011; Baker and Dransfield, 2016; Muscarella et al., 2020).

Rhynchophorus ferrugineus (Coleoptera: Curculionidae), commonly known as the red palm weevil, is a highly destructive invasive insect that poses the most significant threat to nearly 20 palm species including *Phoenix dactylifera* and *P. canariensis* as well as coconut (European Commission, 2011; Giblin-Davis et al., 2013). Adult *R. ferrugineus* females lay clutches of 200–300 eggs in various locations on the palm, particularly the crown (uppermost part) near new growth, at the base of young leaves, or in open wounds. The newly hatched larvae exclusively feed on the soft inner tissues of the palm, discarding fibrous material and causing plant death (Murphy and Briscoe, 1999; European Commission, 2011; Giblin-Davis et al., 2013). This insect causes significant economic losses estimated to be US$ 15 million annually (International Plant Protection Convention [IPPC] Secretariat, 2021). Native to Southeast Asia and Melanesia, *R. ferrugineus* has rapidly expanded geographically since the 1980s across Asia, Africa, Europe, America, and Australia. The spread of this pest is likely due to palm shoot planting and climate change (Fiaboe et al., 2012; Giblin-Davis et al., 2013). Since their first introduction into Mersin Province, Türkiye, via imported palm trees in 2005, this pest has rapidly expanded, particularly in the southern and western regions of the country (Buyukozturk et al., 2011; Atakan et al., 2012; Tezcan, 2020).

Early detection of *R. ferrugineus* is difficult and presents a significant challenge (Rasool et al., 2020). Typically, palm deterioration signifies infestation and only manifests after substantial damage has occurred. The subsequent hollowing of the trunk compromises the

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structural integrity of the palm, rendering it susceptible to catastrophic collapse (European Commission, 2011; Giblin-Davis et al., 2013). In most instances, an attack by *R. ferrugineus* proves fatal irrespective of the size of the palm species. Larvae feed inside the growing point of the palm, weakening the structure and potentially killing the tree (IPPC Secretariat, 2021). While visual inspection offers a method for detecting symptomatic palms, it cannot definitively confirm the presence of larvae or adult weevils within the trunk. Also, the cost of removing and replacing heavily infested palm trees can reach millions of dollars per year (Ge et al., 2015; IPPC Secretariat, 2021).

Various methods are used to control *R. ferrugineus*, including removing infested trees, insecticides such as neonicotinoids and abamectin, insect-killing nematodes, and pheromone traps. Synthetic chemical insecticides are delivered through trunk injections or by soaking entire trees in insecticidal solutions (Aziz, 2024; Hoddle et al., 2024; Husain et al., 2024a; Omer et al., 2025; Rasool et al., 2024). However, drilling holes for trunk injection is an invasive procedure that can harm the palm itself. Furthermore, the overuse of insecticides can lead to the development of resistance in *R. ferrugineus* populations. In the case of edible palm crops, unacceptable residue levels of insecticides within the fruit poses a potential health risk for consumers (Ferry and Gómez, 2002; Aziz, 2024; Hoddle et al., 2024).

Effective management of *R. ferrugineus* infestations in palms requires the development of alternative methods that must be highly accurate, user-friendly, readily automatable, cost-effective for large-scale deployments, and possess long-term field durability. The field of electronic sensing offers promising avenues for the development of novel early detection tools (Rasool et al., 2020; Omer et al., 2025). Electronic sensing involves strategic placement of electronic nose arrays or biosensors within the crowns of individual date palms in commercial groves (Hoddle et al., 2024; Mendel et al., 2024a; Mendel et al., 2024b). These sensors can be designed to detect species-specific aggregation pheromones. Real-time data on pheromone detection can be linked to GPS-tagged palms and transmitted via the Internet of Things (IoT). This would provide rapid and precise information on potential new infestations at the individual tree level, facilitating swift management interventions (Koubaa et al., 2020; Stevanoska et al., 2020). Similarly, the development of highly attractive dry traps or traps with no bait could significantly improve the efficacy of this approach. Proactive surveillance programs utilizing these novel technologies would enable early detection and containment efforts in areas susceptible to weevil invasion. This will increase the likelihood of eradicating nascent populations and enhance control measures within commercial production zones.

This field study investigated the effectiveness of a seismic sensor system to detect *R. ferrugineus* larvae on the palm trees in the İzmir Metropolitan Municipality Culture Park area in 2023–2024. Infested trees were treated with an appropriate insecticide using trunk injections and the effect on infestation was assessed.

2. Material and methods

2.1. Installation of early detective seismic sensor system

Agrint IoT seismic sensors (loTree, Agrint Rockville, MD, USA) are sensing devices that uses a microelectromechanical system. They are a variation of the seismic intrusion sensors to detect *R. ferrugineus* larvae in stem colonization. The seismic sensor system is calibrated to distinguish between normal vibrations within a tree (e.g., from movement of fluids, wind, or rain) and those indicative of infestation by a trunk boring insect, thereby detecting the vibrations caused by feeding *R. ferrugineus*. This information can be used for timely intervention, particularly targeted pesticide applications (Figure 1). This device was used in this field study. The sensors were installed approximately 100–130 cm below the crown of 756 palm trees in the İzmir Culture Park area (38°25′42″N, 27°08′44″E) according to the manufacturer's recommendations (Figure 2). One sensor was installed per tree. There were approximately 800 palm trees in the park area. The majority of these trees are *Washingtonia* sp. (660 trees) followed by *P. dactylifera* (96 trees) species. The trees were approximately 20 years based on the information from park officers and the height of *Washingtonia* palm trees (approximately 15–30 m). Because of the height, a basket crane was used when placing sensors on trees.

A gateway was mounted on a high tree in the middle of the park. This part of the system collects the data from the sensors and transmits the information directly to the end users' application on their cellular phones via the internet.

The seismic sensing device is comprised of a microelectromechanical system that has a detection range of 130 cm. It determines insect activity by measuring seismic vibrations generated by larvae. The metallic rod inserted into the tree receives the vibration signals at intervals ranging from 1 to 24 h; however, a positive reading event triggers a shortened interval of 2 h. Based on the frequency of the vibrations caused by trunk boring pest, the sensor collects the seismic vibrations at intervals (one interval = one reading event) and converts these data into electronic signals. The interval data are used to calculate the seismic value using the formula:

$$\text{Sensor value (\%)} = 100 \times \frac{\text{Positive reading events (in the last 12 days)}}{\text{Total reading events in the last 12 days}}.$$

This is then compared with the healthy control trees. The sensor stores the signals until they are transmitted via Bluetooth (Bluetooth SIG, Kirkland, WA, USA) between

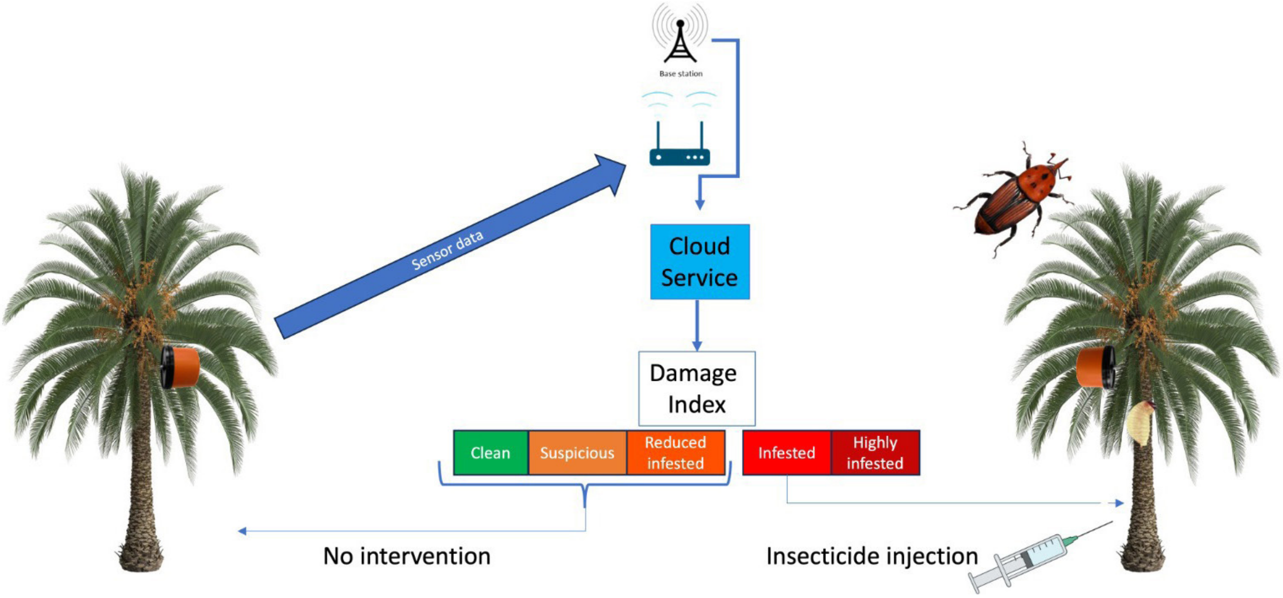

Figure 1. Illustration of the Agrint IoT seismic sensors system (modified from Mendel et al., 2024a).

Figure 2. Installed sensor on a palm tree.

several sensors in the field and the gateway. The rate of insect-produced signals is used as a proxy for palm damage. Finally, decision control and surveillance monitoring were performed by the machine learning algorithm embedded in the Agrint IoTree device (Agrint Ltd., Rockville, MD, USA) via Microsoft Azure Cloud (Microsoft Corporation, Redmond, WA, USA). According to the data collected, the system groups the trees as clean, suspicious, or infested. More details on the decision-making process are not available due to intellectual property rights of the sensor manufacturer (Mendel et al., 2024a). Previously infested trees are monitored to determine reduced infestation. This seismic sensor has 95% accuracy and has been utilized and validated in various studies (Mendel et al., 2024a).

When calculating the percentage of infested trees, inactive sensors were subtracted from the total sensors and infested, high infestation, and reduced infestation were all considered as infested.

2.2. Injection of insecticides into the infested palm trees

Infested trees were injected with insecticide starting in November 2023. Confidor SL 200 insecticide (Bayer Crop Science, Leverkusen, Germany; a.i. 200 g/L imidacloprid) was injected into the trunks of infested trees according to the seismic sensor data. For this purpose, a hole (40 cm deep, 8 mm diameter, 30° angle) was drilled into the trunk with a cordless hand drill. A plastic Arborplug (No. 4 black; Arborjet, Woburn, MA, USA) was inserted to seal the hole and prevent air contact. Twenty milliliters of insecticide were injected into the hole using a 50 mL syringe (BD Plastipak, Franklin Lakes, NJ, USA). The effectiveness of the insecticide was evaluated based on insect activity, as measured by the seismic sensor system.

3. Results

This study monitored the health of 756 palm trees registered in the İzmir Culture Park area. Before the study resumed, the number of palm trees was around 1000 but approximately 200 palm trees had died and were cut down due to *R. ferrugineus* damage. The loss of such large trees in the park area has economic consequences and has caused public concern. Fifteen days after placing the sensors on 381 palm trees, information about their status was obtained. According to the first data received in June 2023, only 3 out of 381 trees (0.78%) were infested (Table). All of the infested trees were *P. dactylifera*.

The number of installed sensors was gradually increased to 756. In March 2024, 670 palm trees out of 756 trees were completely clean in terms of *R. ferrugineus* infestation. Eight trees were infested (7 infested and 1 with

Table. Data obtained from the seismic sensor system used to detect *R. ferrugineus* larvae on palm trees in the İzmir Metropolitan Municipality Culture Park area from 2023 to 2024.

Dates	Total sensors	Clean	Suspicious	Infested	Reduced infestation	Inactive sensors	Infested (%)	Insecticide efficacy (%)
June 2023	381	370	6	3	0	2	0.78	-
July 2023	384	368	10	0	0	6	0	-
August 2023	387	372	14	0	0	1	0	-
September 2023	493	464	21	2	0	6	0.41	-
October 2023	508	425	21	3	0	59	0.66	-
November 2023	566	470	17	3	0	76	0.61	-
December 2023	658	529	16	3	2	108	0.91	66.6
January 2024	756	710	26	6	1	13	0.94	33.3
February 2024	756	679	42	7	1	27	1.09	16.6
March 2024	756	670	44	8	3	31	1.51	42.8
April 2024	756	654	45	18	6	33	3.31	75
May 2024	756	655	32	27	6	36	4.58	33.3
June 2024	756	646	36	26	10	38	5.00	37
July 2024	756	653	29	21	9	44	4.21	34.6
August 2024	756	651	32	14	11	48	3.53	52.3
September 2024	756	665	15	15	5	55	2.85	35.7
October 2024	756	668	10	16	6	56	3.14	40

high infestation) and 44 trees were suspicious (Table). In September 2024, 665 out of 726 sensor-active palm trees were clean and 15 trees were infested (Table; Figure 3). Considering the number of trees that needed treatment (infested) from June 2023 to October 2024, the highest rate was 5% in June 2024, while the lowest rate was 0% in July and August 2023 (Table; Figure 3). The seismic sensor system also provides a satellite image showing the position of sensor-active palm trees and which ones are clean and infested (Figure 4). We monitored the remaining trees for 17 months and observed that the infestation rate varied between 0% and 5% (Table; Figure 3). A targeted control approach was adopted using Confidor SL 200insecticide (Bayer Crop Science; a.i. 200 g/L Imidacloprid), which was injected into the trunk. The efficacy of the insecticide during this surveillance period was 16–75%. The remaining trees were healthy, so there was no need to treat the clean trees. *R. ferrugineus* larval mortality was observed between 8 and 12 days after the insecticide injection. The seismic sensor system first categorized these trees as having reduced infestation status and then reported that they were clear after 15 days (Table). Two of these palm trees were opened and examined. No live larva were found and only three dead larvae were recovered.

4. Discussion

Our study monitored the health of palm trees registered in the İzmir Culture Park area. These palms have been threatened by *R. ferrugineus* as over 200 trees were lost from the park due to pest infestation. Palms are slow-growing arboreal monocots, so their loss has economic consequences and causes public concern. Seismic sensors were installed on the remaining palm trees registered in the İzmir Culture Park area, and their status was monitored for over a year. Infestation rates varied between 0% and 5%, and all the infested trees *P. dactylifera*. Infested trees were verified by identifying tunnels opened by the larvae and frass accumulation. The bark of some trees was removed for further verification. A targeted control approach was adopted; an insecticide (a.i. 200 g/L imidacloprid) was injected into the trunk. With the seismic sensor method, it was possible to protect trees with much fewer chemicals, labor, and environmental impact. An important advantage of this system is that it can determine whether the larvae inside the tree are dead or alive after application. If the infestation is not completely removed, insecticide can be reapplied. With other pest management methods, the real-time status of tree infestation cannot be monitored and infestation cannot be detected until the tree starts to die, which is too late.

Other pest management methods include cultural techniques, like burning dead tree trunks to destroy immature larvae, cutting down the infected palms, fertilization and irrigation, mass trapping. Other methods include monitoring, early detection, applications of acoustic devices, male sterility techniques, host plant resistance, entomopathogenic nematodes. Insecticide applications, including fumigation or application of natural substances, are used to combat *R. ferrugineus* infestations in palm trees (Aziz, 2024; Hoddle et al., 2024). The most common

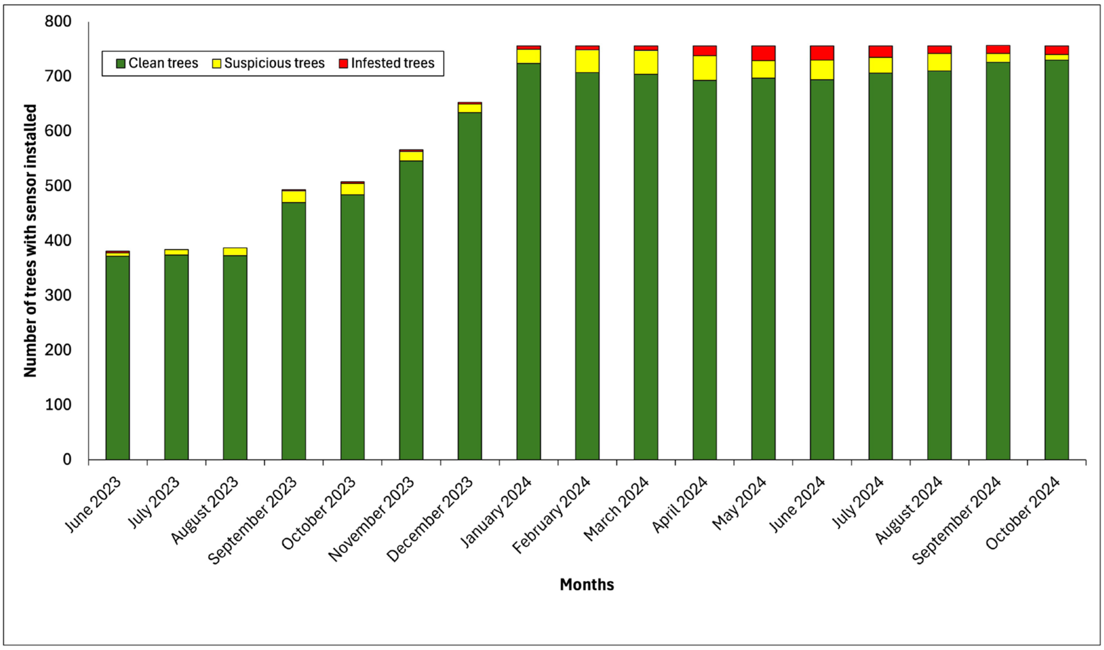

Figure 3. The red palm weevil infestation status of palm trees in the park area in each month.

Figure 4. View of palm trees installed with seismic sensors in the İzmir Culture Park area.[1]

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[1] Google Maps (2024). İzmir Culture Park area [online]. Website https://www.google.com/maps [accessed 10 October 2024].

method is to prevent adult *R. ferrugineus* from laying eggs by spraying the crown area of trees with a contact insecticide several times a year, especially during periods of adult insect activity (Abraham et al., 1998). However, the excessive use of insecticides means that most of the chemicals disperse outside the target area. This can also have negative effects on the environment, other animals, and people. This approach is particularly problematic in park areas with high human density, often leading to public backlash. The high cost of chemicals and labor associated with this method make it less desirable (Ferry and Gómez, 2002; Aziz, 2024; Hoddle et al., 2024). The disadvantage of this method is that insecticide is applied to all trees indiscriminately, regardless of whether they are infested by *R. ferrugineus* or not. Injecting excessive amounts of chemicals into the tree damages the vascular system after a while. Once a tree has been injected, the puncture wound can serve as a gateway for insects, fungi, and other pathogens (Archer and Albrecht, 2023; Shang et al., 2024).

Developing more accurate methods for identifying infected trees could enhance the efficiency and cost-effectiveness of entomopathogen applications. Combining these detection methods with environmentally safe control strategies, such as the use of biological control agents or cultural practices, could further improve their effectiveness. Entomopathogenic nematodes (Elawad et al., 2007; Satheeja Santhi et al., 2015; Rehman and Mamoon-ur-Rashid, 2022) and entomopathogenic fungi have shown potential as biological control agents for *R. ferrugineus*. Entomopathogenic fungi can be applied through spraying (Ment et al., 2023; Sabbahi and Hock, 2024) or by injection (Bekhiet et al., 2018; Husain et al., 2024b). For instance, *Beauveria bassiana*, *Metarhizium anisopliae*, *B. brongniartii* and *Purpureocillium lilacinum* isolates were effective against both *R. ferrugineus* larvae and adults, demonstrating significant mortality rates as high as 51–81%, as well as strong ovicidal properties that reduce egg hatching rates. Infected adults transmitted the disease to healthy individuals, so the fungus could potentially spread naturally within *R. ferrugineus* populations (Alwaneen et al., 2024). While these bioagents may have higher initial costs, they can be more cost-effective in the long term by reducing the need for repeated chemical treatments. The laboratory results for entomopathogenic fungi are promising, but field trials are necessary to evaluate their efficacy in real-world conditions.

Seismic sensors offer a promising tool for early detection and prevention of *R. ferrugineus* infestations in parks. In other areas where palm trees are densely distributed, such as roadsides and nurseries, careful consideration should be given to the costs, benefits, and potential challenges associated with the implementation of seismic sensors. The sale of infested palm trees is the most important reason why *R. ferrugineus* have spread so rapidly. Early infestation of palm trees can be determined by a seismic sensor and clean trees can be certified before sale. This could prevent and/or reduce the spread of this pest. It may be possible to effectively control the spread of *R. ferrugineus* to other areas or countries and protect palm tree populations by combining seismic sensor technology with other management strategies, such as regular inspections and quarantine measures.

Conflict of interest

The authors declare that they have no conflict of interest.

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Data availability statement

All data has been included in the manuscript and can be requested from the corresponding author.

References

Abraham VA, Shuaibi MAA, Faleiro JR, Abozuhairah RA, Vidyasagar PSPV (1998). An integrated management approach for Red Palm Weevil *Rhynchophorus ferrugineus* Oliv. a key pest of date palm in the Middle East. Journal of Agriculture and Marine Sciences 3 (1): 77-83.

Alwaneen WS, Wakil W, Kavallieratos NG, Qayyum MA, Tahir M et al. (2024). Efficacy and persistence of entomopathogenic fungi against *Rhynchophorus ferrugineus* on date palm: host to host transmission. Agronomy 14 (4): 642. https://doi.org/10.3390/agronomy14040642

Archer L, Albrecht U (2023). Wound reaction to trunk injection of oxytetracycline or water in huanglongbing-affected sweet orange (*Citrus sinensis*) trees. Trees 37: 1483-1497. https://doi.org/10.1007/s00468-023-02440-2

Atakan E, Yüksel O, Soroker V (2012). Current status of the red palm weevil in Canary Island date palms in Adana. Türkiye Entomoloji Bülteni 2 (1): 11-22.

Aziz AT (2024). Red palm weevil, *Rhynchophorus ferrugineus*, a significant threat to date palm tree, global invasions, consequences, and management techniques. Journal of Plant Disease and Protection 131: 9-26. https://doi.org/10.1007/s41348-023-00805-w

Baker WJ, Dransfield J (2016). Beyond Genera *Palmarum*: progress and prospects in palm systematics. Botanical Journal of the Linnean Society 182 (2): 207-233. https://doi.org/10.1111/boj.12401

Bekhiet HK, Ali MA, Ragheb DA, El-Feshaway AA (2018). Pathogenicity of the fungus, *Beauveria bassiana* to the Red Palm Weevil, *Rhynchophorus ferrugineus* under field conditions. Egyptian Journal of Agricultural Research 96 (2): 431-441. https://doi.org/10.21608/ejar.2018.133809

Buyukozturk HD, Kutuk H, Birisik N (2011). Current status of red palm weevil in Turkey. EPPO Bulletin 41 (2): 142-144. https://doi.org/10.1111/j.1365-2338.2011.02449.x

Eiserhardt WL, Svenning J-C, Kissling WD, Balslev H (2011). Geographical ecology of the palms (Arecaceae): determinants of diversity and distributions across spatial scales. Annals of Botany 108 (8): 1391-1416. https://doi.org/10.1093/aob/mcr146

Elawad SA, Mousa SA, Shahbad AS, Alawaash SA, Alamiri AMA (2007). Efficacy of entomopathogenic nematodes against Red Palm Weevil In UAE. Acta Horticulturae 736: 415-420. https://doi.org/10.17660/ActaHortic.2007.736.38

European Commission (2011). The insect killing our palm trees: EU efforts to stop the Red Palm Weevil. Publications office of the European Union. Luxembourg: Office for Official Publications of the European Communities. https://doi.org/10.2772/851

Ferry M, Gómez S (2002). The red palm weevil in the Mediterranean Area. Palms 46 (4): 172-178.

Fiaboe KKM, Peterson AT, Kairo MTK, Roda AL (2012). Predicting the potential worldwide distribution of the red palm weevil *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae) using ecological niche modeling. Florida Entomologist 95 (3): 659-673. https://doi.org/10.1653/024.095.0317

Ge X, He S, Wang T, Yan W, Zong S (2015). Potential distribution predicted for *Rhynchophorus ferrugineus* in China under different climate warming scenarios. PLoS ONE 10 (10): e0141111. https://doi.org/10.1371/journal.pone.0141111

Giblin-Davis RM, Faleiro JR, Jacas JA, Peña JE, Vidyasagar PSPV (2013). Biology and management of the red palm weevil, *Rhynchophorus ferrugineus*. In: Peña JE (editor). Potential Invasive Pests of Agricultural Crops. CABI Invasives Series. Boston, USA: CABI, pp. 1-34.

Hoddle MS, Antony B, El-Shafie HAF, Chamorro ML, Milosavljević I et al. (2024). Taxonomy, biology, symbionts, omics, and management of *Rhynchophorus* Palm Weevils (Coleoptera: Curculionidae: Dryophthorinae). Annual Review of Entomology 69: 455-479. https://doi.org/10.1146/annurev-ento-013023-121139

Husain M, Rasool KG, Sutanto KD, Omer AO, Tufail M, Aldawood AS (2024b). Laboratory evaluation of indigenous and commercial entomopathogenic nematodes against red palm weevil, *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae). Insects 15 (4): 290. https://doi.org/10.3390/insects15040290

Husain M, Sutanto KD, Rasool, KG, Qureshi JA, Aldawood AS (2024a). Translocation and survival of trunk injected *Beauveria bassiana* (Hypocreales: Cordycipitaceae) in healthy date palm trees. Journal of King Saud University - Science 36 (2): 103077. https://doi.org/10.1016/j.jksus.2023.103077

International Plant Protection Convention Secretariat (2021). Scientific review of the impact of climate change on plant pests – a global challenge to prevent and mitigate plant pest risks in agriculture, forestry and ecosystem. Rome, Italy: FAO on behalf of the IPPC Secretariat.

Kissling WD, Balslev H, Baker WJ, Dransfield J, Göldel B et al. (2019). PalmTraits 1.0, a species-level functional trait database of palms worldwide. Scientific Data 6: 178. https://doi.org/10.1038/s41597-019-0189-0

Koubaa A, Aldawood A, Saeed B, Hadid A, Ahmed M et al. (2020). Smart palm: an IoT framework for Red Palm Weevil early detection. Agronomy 10 (7): 987. https://doi.org/10.3390/agronomy10070987

Mendel Z, Voet H, Modan N, Naor R, Ment D (2024a). Seismic sensor-based management of the red palm weevil *Rhynchophorus ferrugineus* in date palm plantations. Pest Management Science 80 (3): 1053-1064. https://doi.org/10.1002/ps.7836

Mendel Z, Voet H, Nazarian I, Dobrinin S, Ment D (2024b). Comprehensive analysis of management strategies for red palm weevil in date palm settings, emphasizing sensor-based infestation detection. Agriculture 14 (2): 260. https://doi.org/10.3390/agriculture14020260

Ment D, Levy N, Allouche A, Davidovitz M, Yaacobi G (2023). Efficacy of entomopathogenic fungi as prevention against early life stages of the red palm weevil, *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae) in laboratory and greenhouse trials. Insects 14 (12): 918. https://doi.org/10.3390/insects14120918

Murphy ST, Briscoe BR (1999). The red palm weevil as an alien invasive: biology and the prospects for biological control as a component of IPM. Biocontrol News and Information 20: 35-46.

Muscarella R, Emilio T, Phillips OL, Lewis SL, Slik F et al. (2020). The global abundance of tree palms. Global Ecology and Biogeography 29 (9): 1495-1514. https://doi.org/10.1111/geb.13123

Omer AO, Alharbi HA, Husain M, Rasool KG, Alwaneen WS et al. (2025). Acoustic sensor-based field efficacy evaluation of three different insecticides—trunk injections against the red palm weevil, *Rhynchophorus ferrugineus*. Sound & Vibration 59 (1): 1787. https://doi.org/10.59400/sv1787

Rasool KG, Husain M, Salman S, Tufail M, Sukirno S et al. (2020). Evaluation of some non-invasive approaches for the detection of red palm weevil infestation. Saudi Journal of Biological Sciences 27 (1): 401-406. https://doi.org/10.1016/j.sjbs.2019.10.010

Rasool KG, Husain M, Alwaneen WS, Sutanto KD, Omer AO et al. (2024). Assessing the toxicity of six insecticides on larvae of red palm weevil under laboratory condition. Journal of King Saud University - Science 36 (7): 103268. https://doi.org/10.1016/j.jksus.2024.103268

Rehman G, Mamoon-ur-Rashid M (2022). Evaluation of entomopathogenic nematodes against red palm weevil, *Rhynchophorus ferrugineus* (Olivier) (Coleoptera: Curculionidae). Insects 13 (8): 733. https://doi.org/10.3390/insects13080733

Sabbahi R, Hock V (2024). Entomopathogenic fungi against the red palm weevil: lab and field evidence. Crop Protection 177: 106566. https://doi.org/10.1016/j.cropro.2023.106566

Satheeja Santhi V, Salame L, Nakache Y, Koltai H, Soroker V et al. (2015). Attraction of entomopathogenic nematodes *Steinernema carpocapsae* and *Heterorhabditis bacteriophora* to the red palm weevil (*Rhynchophorus ferrugineus*). Biological Control 83: 75-81. https://doi.org/10.1016/j.biocontrol.2015.01.003

Shang Q, Lu H, Yang M, Wu Y, Chen Q (2024). The advancement and prospects of the tree trunk injection technique in the prevention and control of diseases and pests. Agriculture 14 (1): 107. https://doi.org/10.3390/agriculture14010107

Stevanoska S, Davcev D, Jovanovska EM, Mitreski K (2020). IoT--based system for real-time monitoring and insect detection in vineyards. In: Proceedings of the 18th ACM Symposium on Mobility Management and Wireless Access; Alicante, Spain. pp. 133-136. https://doi.org/10.1145/3416012.3424634

Tezcan S (2020). Contributions to the distribution of *Rhynchophorus ferrugineus* (Olivier, 1790) (Coleoptera: Dryophthoridae) in Turkey. Munis Entomology and Zoology 15 (1): 118-120.