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An updated overview of the threats, global invasion, and management of the red palm weevil *Rhynchophorus ferrugineus*

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Abstract

Red palm weevil (RPW) *Rhynchophorus ferrugineus,* known by several names as the Asian palm weevil, is a significant pest of palm trees (Arecaceae) in various agro-ecosystems worldwide. The Gulf Cooperation Council Countries (GCC) identified *R. ferrugineus* as a threat to date palm production in the mid-1980s. Since then, scientists and growers have used various techniques to manage this destructive pest. Through its 'Rome Declaration,' the UN Food and Agricultural Organization has recently emphasized the critical requirement to control RPW through cooperative efforts and pledges at the national and international levels to stop this disastrous pest's spread. RPW control and eradication have become exceedingly difficult due to gaps and challenges in nearly every aspect of the current RPW-IPM strategy, especially regarding early detection, absence of efficient biological control agents in the field, poor farmer participation in control programs, and the creation and application of phytosanitary measures. This review summarises the worldwide invasion, available management solutions, obstacles to effective control, and future possibilities.

Keywords: Biological control, Chemical approaches, Pest Management, *Population dynamics, Red Palm Weevil*

Introduction

The most often grown plant in dry and semi-arid areas is the date palm (Phoenix dactylifera L.), one of the oldest fruit plants in cultivation worldwide. Its nutritional, physiological, environmental, and social benefits are primarily socioeconomically significant (Manee et al., 2023). In response, numerous insects prey on date palms, inflicting serious illnesses and negatively impacting the quality and productivity of dates (Naveed et al., 2023). The most significant of these is the red palm weevil, which damages date palms the most economically and depends on them as a host species Yang et al. (2023).

According to El-Shafie and Faleiro (2020), *R. ferrugineus* is a deadly tissue borer that is concealed and hard to find in date palms that are affected in the initial phases of the attack. However, chemical treatment (stem injection) affects these palms (Al-Otaibi,2024). Unlike palms that have reached an advanced stage of attack, they can be salvaged when the larvae inflict substantial tissue damage, rendering the palms untreatable and necessitating their eradication (Al-Dosary et al., 2016). According to Hallam et al. (2012), most palm infections happen around the trunk's base near the soil.

Growers of date palms invest a significant portion of their profits in several pest management techniques to get rid of this weevil. In Saudi Arabia alone, RPW control expenses for palm farms are nearly USD 8 million annually (Kassem et al., 2020). This paper will examine the available data on the shortcomings and difficulties in managing *R. ferrugineus* at the moment, as well as the prospects of the current control techniques. It will also recommend a workable, multifaceted strategy for controlling the species.

2. The most damaging pest insect to palm trees is R. ferrugineus.

2.1. Biology and Life Cycle

According to Maso (2015), the (RPW) is a member of the Dryophthoridae family in the order Coleoptera. The life cycle of the holometabolous insect RPW consists of four stages: egg, larva, pupa, and adult (Figure 1). The female can lay as many as 200–500 eggs in her lifetime due to her high fecundity. The RPW can produce four generations yearly, depending on the host and environmental factors. Numerous authors have extensively investigated weevils' morphology and life cycle (El-Shafie and Faleiro, 2020; Mohammed et al., 2021). The eggs are elongated (2.5 × 1 mm) with a shiny white, turning yellowish white or cream near hatching. A recently hatched larvae measure about 5 × 2 mm and weigh about 1 mg. At the same time, the final larval instar can reach 5 × 2 cm, weigh between 4 and 7 g before pupation, and is characterized by biting mouthparts. The final larval instar forms a barrel-shaped (Abdel-Banat and El-Shafie, 2023).

There are typically two stages that make up the pupal stage. The pupa is roughly 25 to 35 mm during the first three-day pre-pupal stage. During the second pupal stage, lasting 12 to 20 days, the pupa transforms from cream to brownish (Bait-Suwailam, 2021). It acquires a lustrous surface that is grooved and reticulated during its development. The pupa typically measures 35 × 15 mm in size at this stage.

Finally, the adult RPW develops with a long, curving rostrum (Saleh and Ertunç, 2022). The female RPW has a more slender and somewhat longer naked rostrum dotted with tiny brown setae than the male. Within the eight days or so that the adult spends in its cocoon, it develops into a sexually mature state. According to Martin et al. (2015), the lifespan of an adult male is 113 days, compared to 76 days for a female. Adults can fly great distances and cover large areas on foot. A female RPW can produce over five million weevils in four generations during her lifetime (Hoddle et al., 2021).

2.2. Pest Status

Attacking more than 30 different species of palm trees, one of the most common invasive pest species worldwide is the RPW. More specifically, according to Giblin-Davis et al. (2013), the range of hosts for the RPW increased from just four species in the mid-1950s (Nirula, 1956) to 40 species in various locations known for growing palm trees. The RPW has benefited from its ability to travel and spread into new geographic regions by trading afflicted palms, permitting the spread of these invasive populations to other palm species (Faleiro,2006). Moreover, RPW's ability to withstand cold temperatures (León-Quinto and Serna,2022) has facilitated the colonization of new environments.

In the late 1900s, *R. ferrugineus* started to damage the Gulf region, eventually expanding to other areas (Giblin-Davis et al., 2013). The RPW is an excellent flyer with a top speed of up to 50 km/d (Hoddle et al., 2015). In the last 30 years, the weevil has spread to 49 nations in Asia, Europe, Africa, and the Caribbean as a result of the transportation of infected palms and palm offshoots for landscaping or the production of dates (El-Shafie and Faleiro, 2020) (Figure.2). Despite the advancement of innovative methods for early infestation detection (Kurdi et al., 2021), observable indicators of infestation frequently emerge after significant harm to the plant has occurred, making efforts to salvage the tree ineffective.

The removal of palm palms significantly impacts the crops and livelihoods of the farmers in the area. In Saudi Arabia, more than 80,000 date palm trees are afflicted with RPW, resulting in an economic burden of over 8 million USD allocated for management and eradication efforts, with a 5% infestation rate (Rasool et al., 2015; Kassem et al., 2020). According to Mohammed et al. (2020), most impacted nations have depended on field traps and artificial pesticides to stop the RPW's spread. Nonetheless, as pesticides can destroy biological diversity, their widespread usage may not be sustainable. Furthermore, reports of pesticide resistance have been made for many years involving populations of RPWs (Denholm et al., 2002; Wakil et al., 2018). Many concepts have been used in place of traditional techniques to aid in the eradication of RPW and ensure the survival of palm trees (Liu et al., 2021). Red palm weevils have been eliminated from the Canary Islands in Spain because of scientifically based programs and sufficient funding (Lee, 2001).

2.3. Host distribution and infestation symptoms

According to reports, *R. ferrugineus* attacks 40 different kinds of palm trees worldwide. The most commonly preferred hosts are the coconut palm, date palm, and canary island date palm (Faleiro et al., 2014). However, Abraham et al. (1998) state that a date palm infected with *R. ferrugineus* will exhibit one or more of the following symptoms: the pupae surrounding an infested palm, dripping with brownish fluid and palm tissue expelled by feeding grubs, which has a distinctive fermented odour; the presence of adults and pupae at the base of the fronds; and the toppling of the trunk in cases of extremely severe and extensive tissue damage (Figure. 3).

Due to the highly aggregated character of the *R. ferrugineus* population, infestations frequently occur in clusters (Faleiro 2006). These infestations are commonly caused by adult invading insects that travel short distances (Hoddle et al., 2015), which may also contribute to the pest's aggregation. According to Abraham et al. (1998) and Soroker et al. (2005), there is a second peak in weevil captures in the Middle East between October and November, following the peak activity observed between March and May.

3. Current RPW management programs

With the recent rise in date palm farming, many younger plantations vulnerable to *R. ferrugineus* attacks—less than 20 years old—have appeared. According to Faleiro et al. (2012), more than half of the date palms throughout the Middle East and North Africa are considered younger than 20 years old. The threat posed by *R. ferrugineus* in date palms is now being addressed by several control measures that have been developed (Mohammed et al., 2020; Manee et al., 2023). Using a food-baited-pheromone (ferrugineol) trap-based integrated pest management (IPM) approach, *R. ferrugineus*, the date palm, has been managed in multiple countries (Al-Otaibi, 2024). This strategy involves finding and removing hidden breeding sites, such as closed and neglected gardens, and maintaining crop and field sanitation.

Additionally, pest surveillance is carried out through pheromone traps (monitors) and periodic field surveys to detect infestations. Mass trapping of adults in endemic pockets is also carried out, and palms are checked to identify infestations; chemical treatments are preventive and curative, and severely infected palms are eradicated (Faleiro 2006). However, to attack *R. ferrugineus* in date palms, this article provides an overview of the critical IPM method and case examples. We also discussed how biological control might be used to fight *R. ferrugineus* in date palms. Below is an overview of possible early detection methods and main control strategies for *R. ferrugineus* in date palms.

3.1 Infected detection in palms

An effective RPW-IPM program depends on the early detection of infection; at the moment, visual inspection of palms is a commonly used method to identify contaminated palms. It is crucial to disrupt the pest cycle by placing an affected palm before the emergence of adults. Depending on the topography, palm density, and field cleaning practices, a skilled individual can examine 200–300 date palms daily. A routine check of date palms under 20 should be conducted at 45-day intervals. El-Shafie and Faleiro (2020).

The FAO standards for RPW management include specifics on the techniques for visually inspecting the date and Canary Island palms. Several nations are researching to create an early detection tool that is both affordable and easy to use. Researchers are looking at advanced approaches like satellite/IoT, acoustic detection, infrared cameras, thermal imaging, and chemical signature detection (Mankin, 2019; Ashry et al., 2020). To identify an RPW-infested palm, however, farmers must rely on visual (manual) inspection because these methods are expensive and necessitate the installation of complex apparatus that is difficult to use and requires expert personnel.

3.2. Trapping of phenomenon

The use of food-baited (natural kairomone) bucket traps Since Hallett et al. (1993) discovered the male-produced aggregation pheromone (ferrugineol) for RPW, there has been widespread use of monitoring and mass trapping activities in the field. Many nations have studied trapping methods, including the role of co-attractants, food bait, release rate, lures, color, and food bait servicing (replacing food bait every few days) (Figure 4).

The inspection of palms for pests can be made more efficient and focused with the use of pheromone trap captures. Priority should be given to inspecting the palms surrounding the traps with more excellent weevil catch rates, contingent upon the availability of human resources. Pheromone trapping should be used with other RPW-IPM strategies since, as El-Shafie and Faleiro (2017) found using controlled olfactometer tests, only a portion of the adult population responds fortunately to the pheromone lure.

Adopting the best trapping protocols is crucial for food-baited RPW pheromone traps. These protocols should address trap design, color, density, servicing (regular replacement of food bait), positioning, lure appeal longevity, etc. El-Shafie and Faleiro (2020) state that using subpar trapping techniques will harm the effectiveness of the trapping process and hence restrict the accomplishment of the control program. Certain nations use a little container within the bucket trap to hold the food bait and water. A lot of the time, this container is too small to carry the necessary amount of bait or falls into the bucket, draining the water and making the food dry, negatively affecting the bait-lure interaction and trap effectiveness. Therefore, it is advised to put the necessary quantity of food bait (150–200 g of dates) into the bucket trap's one-litre water reservoir. The food bait and water in the trap must be replaced every two weeks. Economic logic would dictate that food baits that are easily obtained locally and have a strong attraction should be employed as trap baits.

Nonetheless, it is advisable to use pheromone lures that are highly attractive and have a long field life. It is unacceptable to throw away outdated lures in the field or transport them to the homes of field personnel. These will either be buried far below or returned to the operations unit. However, they might also significantly raise the price of a program for area-wide management (Oehlschlager, 1998; Al-Saoud, 2013; Al-Otaibi, 2024).

In surveillance programs, trap density is determined by placing one trap every kilometer along motorable roadways. Depending on the severity of the pests, mass trapping programs can use one to four traps per hectare (Faleiro et al. 2011). Position the bucket traps so that about half are beneath the shade. Avoid positioning traps directly on juvenile palms. However, each trap must be geo-referenced and numbered to mobilize resources around traps with high weevil catch rates and conduct periodic reviews of the field conditions(El-Shafie and Faleiro, 2020).

Despite being the most widely used RPW pheromone trap, replacing the food bait regulated is laborious and unsustainable over time, particularly in programs for area-wide control. El-Shafie and Faleiro (2011) have tested and employed the attract-and-kill strategy, which does not involve bait or traps, to control the growing adult population of RPWs (Al-Saroj et al., 2017). Evaluating the expenses of implementing these methods with the conventional food-baited pheromone trap is crucial before implementing them in an area-wide control campaign (Potamitis et al., 2009; Al-Otaibi, 2024). The perfect RPW pheromone trap would not require maintenance and would automatically provide data on weevil capture to the operations control unit around the clock.

3.3. Chemical detection

As a potential early detection method, identifying the chemical signatures released by a date palm afflicted with *R. ferrugineus* has been researched. In this regard, Nakash et al., 2000 verified that Golden Retriever dogs could effectively smell and identify the seeping fluid taken from date palms infested with *R. ferrugineus*. However, Al-Dosary et al. (2016) found no evidence to support the claim that trained dogs could identify the infected palm on the spot. In large plantations, their use may be limited, especially in the summer when temperatures are high. According to Soroker et al. (2013), dog-assisted detection may benefit palm inspection at nurseries, ports of entry, and quarantine facilities. It has been proven possible to identify volatiles from insect-infested plants using electronic gas sensors (Magan, 2001).

To stop *R. ferrugineus* from spreading, date plantations in endemic hotspots are treated with insecticides by applying preventive sprays and showers. It has previously been advised to use insecticide to protect recently injured areas from incoming female weevils and stop their eggs from hatching (Abraham et al., 1998). Such palms are known to recover after curative pesticide treatments administered during the early stages of assault using stem injection procedures (Al-Dosary et al., 2016). It is necessary to shred palms that have sustained significant tissue damage and extensive tunneling in the later stages of the attack to eliminate the pest, which frequently harbors overlapping stages. About 20% of the infected date palms are eradicated at the present detection levels (Al-Shawaf et al., 2012). It is not advisable to eliminate the bug by burning it since the concealed stages of the infestation are frequently located deep within the palm tissue, where the heat produced might not be deadly.

3.4. Detection of thermal imaging

Infrared cameras are a technique for detecting temperature rises in infected palms. An assessment of recent developments in remote thermal imaging technology by Soroker et al. (2013) suggests that it may be possible to map the variations of canopy temperature over broad areas by obtaining spatial information on surface temperature. More research and development of this technique are required to identify palms infected with *R. ferrugineus* at the earliest stage of an infestation. El-Faki et al. (2015) recently offered essential baseline data on the temperature profiles of RPW-infested date palms to facilitate the development of a real-time sensor fusion system for the nondestructive early detection of insect infestation. To effectively battle the threat of RPW-infested date palms, dependable and user-friendly early detection devices are required to identify infected palms early in the attack. According to Al-Dosary et al. (2016), unless dependable and user-friendly infestation detection devices are created and used, the only method for locating RPW-infected date palms will be visual detection through human inspections.

4. Agro-techniques, phyto-sanitation, and host plant resistance

Agro-techniques related to date palm production, such as varietal preference, are closely associated with palm and field, which is crucial for effectively managing RPW in date plantations (Abraham et al., 1998; Al-Ajlan, 2008). Because the protection mechanisms against RPW that occur naturally are not well understood, they are not used to control this deadly pest of palm trees. Regarding varietal preference, research indicates that high-sugar date palm cultivars promote growth and development, whereas high-calcium date palm cultivars with hard tissue impede RPW growth and development (Faleiro 2006; Al-Ayedh 2008). RPW greatly preferred the well-known date palm cultivar Khlas (Faleiro et al., 2014). The recently identified regulatory and protection mechanism known as gene silencing, or RNA interference (RNAi), in animals and plants can reduce insect pests, such as *R. ferrugineus*, in date palms. It also offers a new and distinct way to create plant varieties resistant to these pests (Niblett and Bailey, 2012).

According to Sallam et al. (2012), who inspected 393 date plantations spread across 234ha in Saudi Arabia, nearly 90% of the infestations occurred on the palm trunk between 0 and 100 cm above the ground, which was noted to record infestations and collect additional data. The date palm's crown is occasionally infected with *R. ferrugineus*, mainly in areas with high weevil activity. The findings of Sallam et al.'s (2012) study also supported earlier findings (Abraham et al., 1998), showing that the age range of 6 to 10 years old had the highest percentage of infestations (36%). Furthermore, date palms with no offshoots had the highest infestation rate (79%). It suggests that when offshoots are removed, the palm becomes vulnerable to RPW attack, particularly when fronds are pruned, necessitating insecticide application, as Abraham et al. 1998, to protect newly injured palms. Concurrently, it is essential to note that palms with multiple offshoots make it more challenging to examine the palms to identify infections in agreement with the results of Aldryhim and Khalil (2003), who found that increased soil moisture and flood irrigation give adults a temporary place to live and raise the risk of RPW infestation in date palm.

5. The Sustainable Control of the RPW via Integrated Pest Management Approach

It is necessary to modify strategies to fit particular ecosystems and adapt IPM to different geographic locations and kinds of palm trees. One of the main issues in developing regions is the cost of implementing modern technology and ensuring accessibility. Pest control results are best achieved by adapting Integrated Pest Management (IPM) tactics to specific ecological and geographical situations. Unfortunately, the widespread adoption of IPM is hampered by technological disparities, financial constraints, and inadequate infrastructure, especially in low-resource areas. By focusing on affordable and easily accessible technology for RPW control, this gap must be closed by focused research, innovation, and capacity-building initiatives. RPW management may be made much more sustainable and efficient by using these technologies worldwide. The preservation of palm ecosystems and the management of the RPW can be accomplished sustainably with IPM. IPM optimizes effectiveness while minimizing environmental impact by combining precision technologies with cultural practices, biological control, targeted chemical control, and monitoring and surveillance. IPM has excellent potential to control RPW infestations and preserve palm plants' lifespan and health, especially with the continuous developments in precise equipment and technology.

5.1. Techniques for Cultural Control: Cleaning, Pruning, and Eliminating Infested Palms

Effective management of the RPW necessitates prioritizing field and crop hygiene to eradicate possible breeding habitats. It's advised to use shredding to destroy palm trees that are severely infested and cannot be rescued. Since green palms don't burn well, weevil stages deep within trees can survive, making fire inappropriate. Recently, applying insecticide to cut or injured palm surfaces is essential as part of phytosanitation procedures after pruning the fronds or removing the offshoots. According to Dembilio and Jaques (2015), this strategy is vital to eliminating palm volatiles that could draw female weevils looking for suitable places to lay their eggs. The following suggested actions should be considered for efficient cultural control of RPW infestations.

RPW infestations can be successfully managed, and palm tree health can be preserved by implementing these techniques. Effective cultivation and management of date palm trees require meticulous attention from growers, as their health and productivity are directly correlated with the measures implemented. Pest infestations are reduced, and field operations maintain date palm tree health. Salah (2019) lists these procedures as selecting offshoots, spacing them appropriately, fertilizing optimally, using effective watering techniques, thinning fruit, clipping leaves, and harvesting efficiently. Al-Ahsa, Saudi Arabia (SA) validated an IPM program for the RPW to assess the effectiveness of field activities (Al-Shawaf et al., 2012). The program's success was evaluated based on data collected from removing infested palms. The results showed that eliminating more than 20% of the infested palm population was unacceptable, emphasizing the necessity for adaptive control measures in cases where the pest population persists.

A previous study offered a thorough procedure for securely extracting and discarding badly contaminated date palms (Ridgway et al., 1990). This procedure involves utilizing colorful tape, spray paint, or straps with specific markings to identify and label severely infected areas. When more than 30% of the trunk tissue is injured at the infestation site, the infestation is considered severe. The palm crown, trunk, and bole regions are treated with the suggested pesticides by soaking, soaking, or showering them as a prophylactic precaution. El-Shafie (2020) states that the infected palms are cut into logs and that different parts of the palm, like trunks and fronds, are then taken to the shredder. While growing perennial crops like palms, farmers frequently select well-known and commercially successful varieties typically grown in their area. However, these preferred cultivars are often quite vulnerable to RPW infestation. Despite several preliminary studies examining the resistance or susceptibility of various palm cultivars to the RPW (Faleiro et al., 2014), there is a substantial information vacuum concerning the investigation and application of host plant resistance against this pest (Naveed et al.,2023).

Moreover, multiple aspects of agro-techniques used in RPW management are crucial. These variables include the best palm density, suitable irrigation techniques, and prompt tissue preservation after removing fronds and offshoots. According to Salah (2019) and Naveed et al. (2023), these procedures are essential for successfully reducing RPW infestations.

5.2. Biocontrol for Regulation of Red Palm Weevil

Predatory insect and nematode introduction, mass rearing and population growth, biological monitoring, natural enemy conservation, and ongoing research and development into new predators and nematodes for sufficient control are some of the crucial steps in managing RPW infestations. Biological control strategies should be chosen and implemented with careful consideration of the local conditions, control measures' efficacy, and methods' compatibility. Through practical and long-lasting management, RPW infestations are intended to be achieved. Many nations have extensively studied biological control strategies for RPW infestations (Faleiro, 2006). A noteworthy study that looked into the efficacy of various sesquiterpenes against the RPW was carried out in South Africa by Hussain et al. (2019). Similarly, AlJabr et al. (2017)

observed that phenylpropanoids have larvicidal and growth-inhibiting properties against the RPW in South Africa.

Furthermore, the larvicidal effectiveness of many concentrated extracts of Piper nigrum seeds against the RPW was assessed by Hussain et al. (2017). Abdullah (2009) investigated the toxicity and pathological consequences of two naturally occurring biopesticides on RPW larvae: precocene II and Boxus chinensis oil. According to Al-Dosary et al. (2016), there is evidence that the marine earwig A. maritima (Dermaptera: Carciniphoridae) preys on RPW eggs and newly hatched larvae. Adult RPWs have been reported to be infected by several entomopathogenic nematode (EPN) isolates (Nurashikin-Khairuddin et al., 2020).

A thorough list of over 50 Rhynchophorus group biological control agents that are successful against weevils was presented by Mazza et al. (2014) in their study. Twelve species of insects, one species of virus, eight species of bacteria, nine species of fungi, yeasts, seven species of nematodes, eleven species of mites, and six species of vertebrates were among them. The best option among these was fungus-based biocontrol agents. They fulfill the criteria for biocontrol in multiple dimensions and are appropriately adapted to diverse situations (Abdullah, 2009; Mazza et al.,2014). Nevertheless, more investigation is required to ascertain whether these mites cause pathology in the weevils. A thorough analysis of the usage of microbial agents for RPW management was carried out by Yasin et al. (2019).

RPWs have been effectively controlled by plant extracts from a variety of species, including clove (Syzygium aromaticum), cardamom (Elettaria cardamomum), citronella grass (Cymbopogon nardus), French marigold (Tagetes patula), and Ceylon (Cinnamomum zeylanicum) because of their insecticidal qualities (Naveed et al.,2023). According to Shapiro-Ilan et al. (2023), at least 13 steinernematids and heterohabditids have been commercialized to control insects due to this production capacity. According to several studies, plant extracts are efficient biological control agents for RPW infestations. Promising outcomes in tackling the problem of RPW infestation have been demonstrated by the symbiotic link between EPNs and the bacteria they are connected with (Naveed et al., 2023).

5.3. Chemical Strategies for Controlling Red Palm Weevils

Developing focused chemical therapies requires understanding the RPW life cycle from egg to adult. The life stages represented particular weaknesses for focused pest control. Chemical strategies can potentially mitigate the RPW while maintaining ecosystem integrity. Creating an environmentally friendly toolkit for managing RPW populations is possible by carefully assessing biopesticides and chitin synthesis inhibitors. The effectiveness and sustainability of these chemical treatments must be improved via ongoing research, innovation, and cooperation; this will ultimately aid in preserving palm trees and the ecosystems they support.

RPW populations are frequently managed with chemical control (Naveed et al., 2023). However, using chemicals to control this pest has several difficulties and factors to consider. These are some salient points: selection of efficacious pesticides, application time, insecticide infiltration, resistance management, environmental factors, regulatory adherence, monitoring and assessment, and integrated pest control (Alhewairini,2018). It is essential to acknowledge that insecticides can be expensive, their overuse may damage the ecosystem, and they might foster the development of chemical resistance in weevil populations (Kaakeh, 2006). In regions with significant RPW infestation, prophylactic spray or shower applications of insecticides are routinely utilized to safeguard date plantations and reduce the proliferation of the weevils (Naveed et al., 2023). However, to inhibit female weevils from ovipositing, pesticides must be administered directly to recent wounds (Naveed et al., 2023). Curative insecticide treatments applied via stem injection procedures work well for afflicted palm plants in the early phases of infestation. Recently, date palm RPW infestations have been prevented and treated with contemporary insecticides (Kaakeh, 2006; Al-Shawaf et al., 2010). Some nations use pressure injectors to inject the stems of infected date palms. Also, to avoid irreversible tissue damage, it is imperative to use caution when applying the insecticide at more significant pressures and ensure the pressure does not surpass 1 bar. (AlDosary et al., 2016) These therapies must be carried out under the guidance of qualified professionals (Wakil et al., 2018). Although synthetic pesticides have historically been used to combat RPW (Hussain et al., 2013), they are unsustainable and dangerous for biodiversity, the environment, and public health (Rani et al., 2021). IPM integrates biological, chemical, and cultural methods with ecosystem health and reduces reliance on pesticides while preserving agricultural profitability, quality, and yield (Alotaibi et al., 2022).

Effective management of RPW in date plantations is frequently achieved using pheromone traps. According to Al-Otaibi (2024), these traps can be suspended from palm trunks, placed at ground level, or partially buried in the ground. Long-term traps hanging on the trunk of a palm tree can be detrimental to its integrity and health. However, using black traps (with funnels, apertures, and no coverings) at ground level is essential to maximize the effectiveness of pheromone traps (Arafa, 2021). Pheromone traps can affect different arthropod groups depending on several criteria, including trap design, placement, and the particular pheromone utilized. Even while pheromone traps are usually made to target specific pests and reduce their impact on non-target species, unforeseen outcomes are sometimes possible (Naveed et al.,2023). It is significant to remember that various insect predators, including lady beetles, hoverflies, tiny pirate bugs, parasitic wasps, and honey bees, prefer certain trap color features.

The lifespan of the lure is extended, and the efficiency of the traps is increased by placing them in shaded regions. In mass trapping programs, the number of traps required is usually determined by the density of pests in the area; typically, this ranges from 1 to 10 traps per hectare (Faleiro et al., 2011). In mass trapping operations in afflicted nations, 4-methyl-5-nonanone, a ketone typically present in certain fruits and plants, is frequently used as a supplement (Hallett et al., 1993). According to Naveed et al. (2023), the pheromone traps are more attractive for female weevils than adult males. As a result, two females are often captured for every male weevil. Since catching female weevils before they start laying eggs helps stop new infestations, this discovery is crucial to managing RPWs.

The RPW and other insects rely on semiochemical chemical signals to facilitate interaction and communication. Pheromones are chemical signals that carry information within a species, and semiochemicals can be classified into two classes according to the transmitter and the recipient of the message (Al Ansi et al., 2022). Prior research on the application of pheromone traps in the IPM of the RPW has concentrated on the following topics: the number of traps per hectare, trap design, colour, kairomones (Naveed et al., 2023), lure sources, and pheromone release rates (Faleiro and Chellapan, 1999; Krishnakumar et al., 2004). The location of the trap (in the middle or at the perimeter of the palm orchard), the surrounding temperature, the source of the pheromones, and the degree of date fruit fermentation (which acts as a kairomone) all affect how many RPWs are captured in pheromone traps (El-Shafie and Faleiro, 2017; Al Ansi et al., 2022).

6. The Influence of Ecosystem Health on RPW Population Dynamics

Understanding how ecosystem health affects the population dynamics of this deadly insect is critical, given the substantial global ecological and economic harm that the RPW causes. The dynamics of the RPW population are influenced by various factors related to ecosystem health, including biodiversity, habitat structure, climate, and human activity. These factors can provide vital information for maintaining sustainable pest management practices. The ability of diverse and healthy ecosystems to provide natural predators and competitors to regulate population growth enhances biodiversity and is essential for controlling RPM populations (Gullino et al., 2022).

RPW populations are significantly impacted by changes in biodiversity, whether due to invasive species, host plant variety, predator-prey dynamics, or ecosystem stability. By analyzing these processes, we can create plans that support biodiversity and capitalize on its potential to lessen the negative impacts of RPW infestations on palm ecosystems (Castex et al., 2018). The distribution and abundance of RPWs are significantly influenced by climate, which includes temperature, precipitation, and seasonal fluctuations. The dynamics and spread of RPW populations may be impacted by climate change and extreme weather events, underscoring the necessity of climate-adaptive pest management techniques (Leon-Quinto & Serna, 2022).

According to Omran and Negm (2020), the distribution and quantity of RPWs are negatively impacted by climate change. RPW reproductive factors, including oviposition and egg hatching, are significantly influenced by temperature, as demonstrated by studies conducted by Dembilio et al. (2012). This effect is more noticeable in areas where mean monthly temperatures are below winter averages, which is typical in most Mediterranean regions (Dembilio et al. (2012). These results demonstrate the possibility that, especially in tropical and marine climates, climate change may decrease RPW quantity and disturb its distribution (DeMarche et al., 2019). Relative humidity harms RPW population abundance, while El-Lakwah et al. (2011) found a favourable link between the two. Peak populations occur at particular periods of the year due to these climatic conditions' effects on the emergence and flying habits of adult RPWs El-Lakwah et al. (2011).

Integrated pest management (IPM) involves using various pest control techniques while reducing environmental effects. However, to implement successful IPM methods, it is essential to comprehend the ecosystem's role in RPW population dynamics (Manee et al.,2023).

7. Challenges with RPW Management and Its Prospects

Numerous obstacles must be overcome to manage the RPW effectively, and initiatives are being made to enhance control strategies and create management opportunities. Comparatively, the RPW can be managed using biological agents, chemical pesticides, and cultural management techniques. Biological control measures might not always be feasible or generally accessible, and weevils have resisted several insecticides. It's critical to create fresh control mechanisms and coordinated strategies. Since the weevils hide inside the palm trees, it can be challenging to identify and track RPW infections early on. Both accuracy and efficiency are limited regarding monitoring methods like pheromone traps and visual inspections. Developments in detecting technologies, such as drones, trained canines, and remote sensing, may make it easier to identify and track weevil populations early on. The RPW may spread quickly over great distances and is incredibly mobile. One of the main ways that it spreads is by human-mediated plant-borne material transfer. Preventing the weevil's spread to new regions necessitates strict quarantine regulations and public awareness initiatives. Regulations and international cooperation can reduce the chance of spread.

Further, to guarantee early detection and the use of control measures, public education regarding the biology of the weevil, symptoms of infestation, and suitable management methods is essential. Research is still being done to create efficient biopesticides targeting the RPW by utilizing microorganisms like bacteria and fungi (Nurashikin-Khairuddin et al., 2022). Compared to chemical insecticides, these biopesticides are a more environmentally friendly option. Pheromone-based attractants and trapping systems can be further developed to improve the effectiveness of mass-trapping and monitoring initiatives. Research is still being done to enhance trap designs and create more alluring synthetic pheromones.

Providing farmers with an economical and effective early detection tool is one of the main obstacles in the strategy's early stages. Numerous laboratories worldwide have investigated the detection of chemical signatures, acoustic signatures, thermal imaging, satellite imaging, and other modern approaches (Massimo et al.,2018; Naveed et al.,2023).

However, visual examination of the palms is still essential to detect plants affected by RPW. Changing the bait and water in food-baited traps regularly and keeping track of weevil captures are two significant drawbacks of employing pheromone traps. Attract and kill (trap-and-bait-free) and dry trapping (ElectrapTM) have helped solve this problem. Nonetheless, weevil capture data collecting techniques still require improvement. A promising advancement for the future would be a dry trap capable of automatically recording and transmitting data related to weevil capture. In addition, to attract and kill strategies, additional research and development are needed for other semiochemical-based approaches to controlling the RPW, such as the "push-pull" technique (Guarino et al., 2013) and the "attract and infect" method (Al-Keridis et al., 2020), which involves dispersing biological control agents (EPFs) using pheromone traps.

Furthermore, when transferring infected palms to a shredder off-farm or at a specified shredding location, there's a chance that weevils could escape. According to Ferry's (2020) suggestion, growers might use small, portable shredders to handle or dispose of highly contaminated palms. Obtaining insights into the situation and making effective judgments about resource allocation depends on regular validation and performance analysis of the control program. We must take this issue on. Since weevil catch in traps and the number and locations of infested, treated, and eliminated palms are important information, accurate record-keeping is essential to effectively validating the control program. Field maps of operational regions can make record-keeping easier by making it possible to plot trap locations and infested palms. People can regularly generate spatial and temporal spreadsheets by charting weevil captures in traps and labelling afflicted palms on maps with different colours. Implementing a systematic data collection procedure connected to a GIS is imperative. Finding contaminated palms that have been spotted using various techniques is made possible by using multiple mapping traps, recorded weevil captures, and tracking temporal and geographical changes in pest distribution (Naveed et al., 2003).

Nothing is known about host plant resistance to the RPW, which opens up new research opportunities (Naveed et al.,2023). According to Naveed et al. (2023), common palm cultivars can acquire resistance against the RPW through both conventional plant breeding procedures and cutting-edge molecular-based technologies. Many nations have mostly state-run RPW IPM programs, with little or no farmer involvement. Socioeconomic studies are critical to improving farmers' participation in the RPW control program, according to Abdedaiem et al. (2017). The items in question include palm injectors, biological control agents, semiochemicals, microwave treatment devices, drones for surveillance, pesticides, and palm shredders. For farmers to access affordable and user-friendly technologies, proper national and regional testing and validation of these IPM instruments is vital.

8. Conclusions

The RPW is still a severe worldwide danger to the survival of palm trees. The main ways that RPW spreads to new regions are through global trade and the movement of infected palm planting material used in landscaping and plantations. Biological control approaches in moderation, mass pheromone monitoring, and agronomic and phytosanitary practices are the main components of the current RPW management strategy. Nevertheless, despite significant international efforts, there are still essential gaps and problems with these management systems. These difficulties include identifying infestations early, maximizing pheromone-baited traps, eliminating heavily infected palms, decreasing the need for excessive insecticide use, and involving farmers more in control initiatives. The future of RPW management may entail validating management programs and testing modern technologies for practical implementation in control initiatives. Understanding how difficult it is to manage RPWs in the field is critical. Still, this pest may be managed with current technologies provided enough resources, the right interventions, and vital planning, coordination, and funding are provided.

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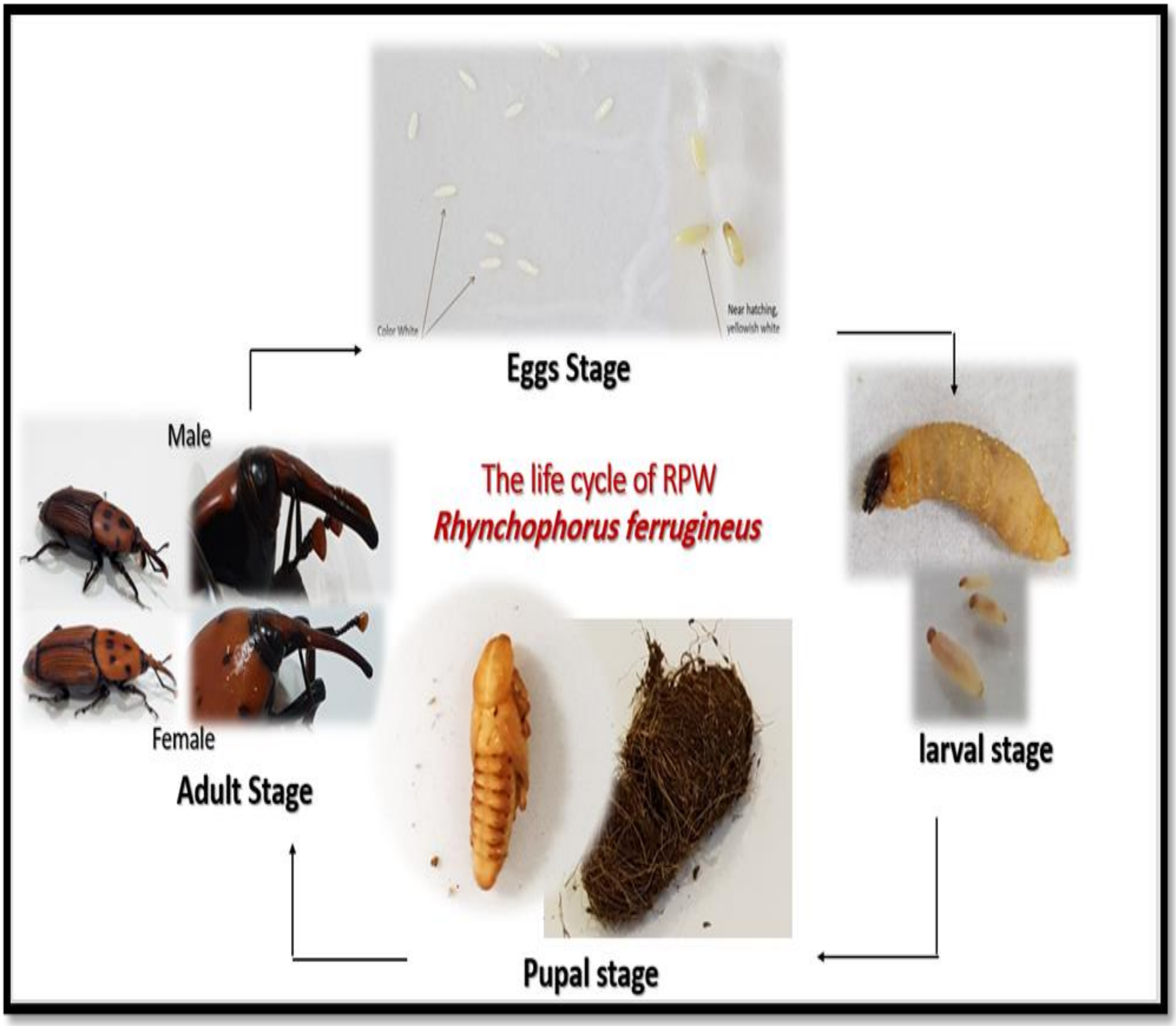

Figure(1). Diagrammatic Illustration of the RPW Life Cycle

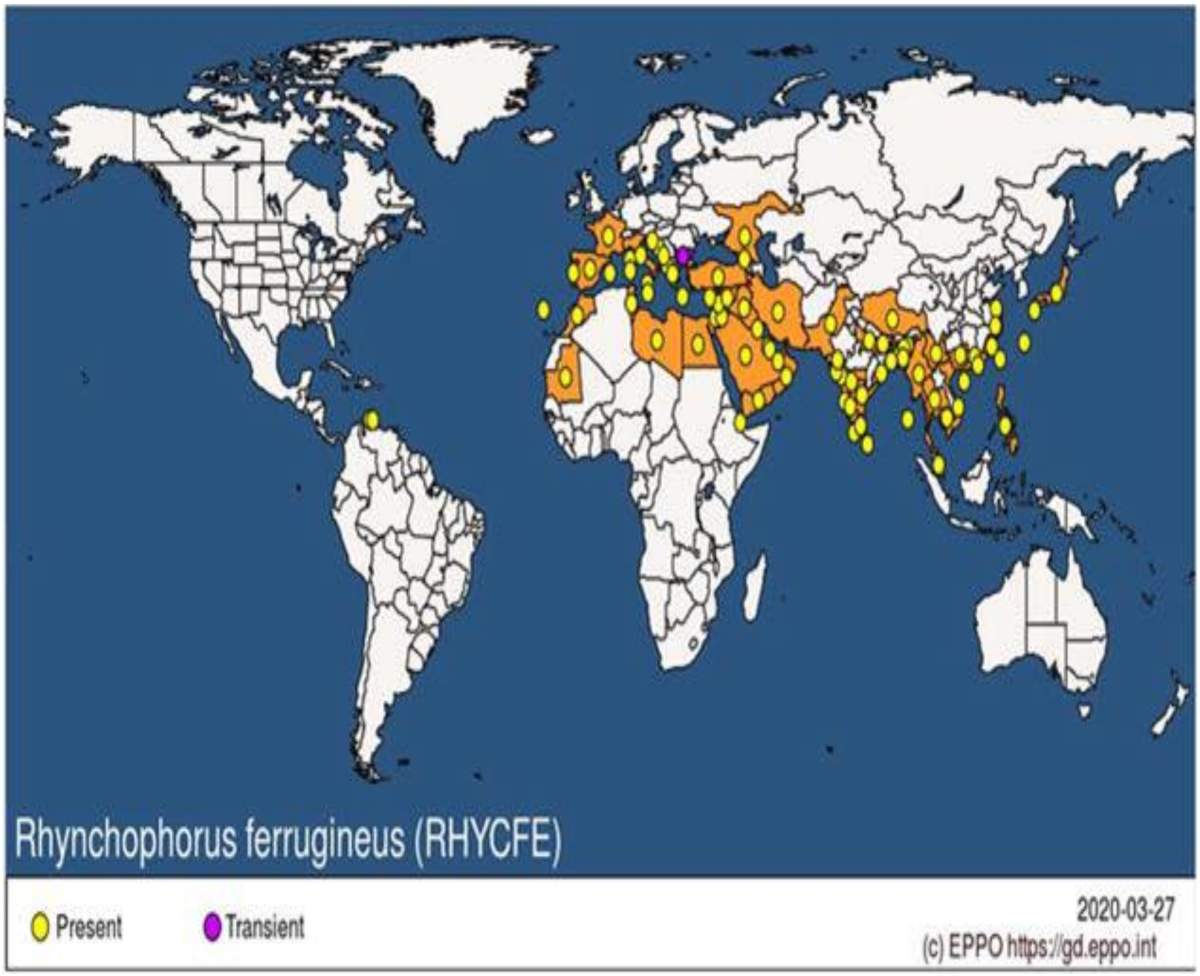

Figure (2). Current RPW Geographic Distribution (Source- El-Shafie and Faleiro 2020).

Figure (3). Illustration damage symptoms on date palm A) larve; B) Brownish viscous fluid; C) Destroyed palm tissue; D) Dry and yellowing of the fronds; E) Death of the palm tree.

Figure (4). Illustration Food baited-pheromone traps