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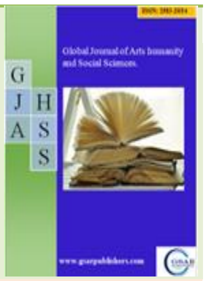

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Artificial Intelligence (AI) extension interventions, for Handling Red Palm Weevil (RPW), in El-Bahriah Oasis, Egypt.

By

Dr. Radwa M. Ata[1], Pro. Emad M. EL-Shafie[1], Pro. Medhat Ezzat[2], Pro. Sally F. M. Allam[3], Esraa Ahmed[4]

[1]Rural sociology and agricultural extension, Dept, Faculty of Agric., Cairo Univ. Egypt.
[2,3,4]Zoology and Agricultural Nematology Department, Faculty of Agriculture, Cairo Univ., Egypt

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Corresponding author
Dr. Radwa M. Ata

Abstract

The Red Palm Weevil (RPW), Rhynchophorus ferrugineus, represents a critical threat to the date palm industry in Egypt, particularly in the vital oases of the Western Desert. While Integrated Pest Management (IPM) is recognized as the most sustainable control strategy, its effectiveness hinges on the knowledge and practices of Date Palm Growers (DPGs). This study, conducted in El-Bahriah Oasis, assessed the current status of RPW management among 156 randomly selected DPGs through a structured questionnaire. The findings revealed a high level of existing knowledge regarding RPW symptoms and control methods, coupled with a strong commitment to applying IPM principles. However, to bridge the gap between knowledge and optimal application, this paper proposes a strategic integration of Artificial Intelligence (AI) into extension services. The proposed AI extension interventions focus on modernizing training, facilitating information dissemination, empowering community-based learning, and establishing rapid response systems. The conclusion underscores that Among the many AI interventions important examples include:

- Gradually integrating AI applications in extension programs, through mainstreaming more innovative AI tools in implementing extension plans and capacity building of RPWs' technicians and progressive DPGs, through Intensively using AI digital applications for more effective dissemination, sharing and exchange of IPM information, practices and experiences.
- Establishing Males, Females or Mixed Farmers' Field Schools to facilitate DPGs' group learning, understanding and applying the best-fit IPM practices.
- Using AI applications in Awareness Raising Campaigns for promoting high quality date production and exports.
- Establishing ground and/or mobile phone hot-lines for timely responding to sudden emergencies, consultation and/or advice requests.

1. Introduction

The date palm (Phoenix dactylifera L.) is a cornerstone of Egypt's agricultural heritage and economy, a status particularly evident in the vital oasis ecosystems of the Western Desert. Beyond their economic significance as primary date-producing regions, these oases are crucial for sustaining biodiversity and ecological stability. However, this vital industry is confronting a severe and immediate threat from the Red Palm Weevil (RPW), Rhynchophorus ferrugineus (Olivier). Globally recognized as one of the most destructive pests of palm trees, the RPW inflicts substantial yield losses, complete crop failure, and mortality of infested trees. The pest's challenge is compounded by the cryptic behavior of its larvae, which tunnel into the palm's heart, often rendering infestations detectable only at an advanced and irreversible stage.

In response, Integrated Pest Management (IPM) has emerged as the most effective and sustainable control strategy. IPM integrates biological, cultural, physical, and chemical methods to manage pest populations in an economically viable and environmentally sound manner. Nevertheless, the efficacy of IPM is fundamentally dependent on the knowledge, attitudes, and practices of the farmers who implement it—the Date Palm Growers (DPGs). While traditional agricultural extension services have been valuable, they often face limitations in timeliness, scalability, and keeping pace with the dynamic flow of pest management information.

This study was conducted in El-Bahriah Oasis, a key agricultural hub in the Western Desert, to evaluate the current state of RPW management among local DPGs. The assessment not only confirmed a solid foundation of grower knowledge and commitment to IPM principles but also identified a critical opportunity to augment these strengths through modern technology. Consequently, this article proposes a suite of targeted extension interventions leveraging Artificial Intelligence (AI). These interventions are designed to enhance the dissemination, adoption, and overall effectiveness of IPM practices against the RPW, thereby securing the long-term sustainability of date palm cultivation in Egypt.

2. Objectives

his study was designed to achieve two core objectives:

1. To determine the proficiency of Date Palm Growers (DPGs) in El-Bahriah Oasis in identifying Red Palm Weevil (RPW) symptoms and control methods, and their dedication to implementing Integrated Pest Management (IPM) practices for sustainable palm cultivation.
2. To identify and define essential Artificial Intelligence (AI)-based extension interventions required for effective RPW management and for optimizing the IPM adoption process

3. Review of Literature

3.1. The Threat of the Red Palm Weevil (RPW)

Rhynchophorus ferrugineus Olivier (Coleoptera: Curculionidae), commonly known as the Red Palm Weevil, represents one of the most devastating biotic threats to palm cultivation globally (Faleiro, 2006). While the pest originated in tropical Asia, its geographical distribution has expanded dramatically in recent decades, with established populations now reported throughout the Middle East, North Africa, the Mediterranean basin, and parts of the Caribbean (Giblin-Davis et al., 2013; El-Sabea et al., 2009). This rapid expansion has precipitated severe economic losses and significant ecological disruption in affected regions.

The Egyptian date palm sector faces particular vulnerability, especially within the fragile agro-ecosystems of the Western Desert oases. The economic impact manifests through two primary channels: direct losses from the mortality of productive trees and the substantial recurring expenditures associated with control measures and quarantine enforcement (Soroker et al., 2021).

Management of RPW presents exceptional challenges due to the pest's cryptic life history. The larval stages develop concealed within the palm trunk and crown, feeding on vital meristematic tissues. External symptoms typically become apparent only after extensive internal damage has occurred, often rendering salvage impossible and leading to sudden palm collapse (Abdel Hafez et al., 2021). This concealed developmental pattern underscores why early detection represents the most critical component of successful RPW management.

3.2. Integrated Pest Management (IPM) for RPW: Principles and Challenges

Integrated Pest Management has emerged as the most sustainable framework for RPW control, emphasizing the combination of multiple, ecologically compatible tactics to maintain pest populations below economically damaging levels while minimizing adverse environmental and health impacts (Dara, 2019).

Comprehensive RPW IPM programs typically incorporate several key components:

Monitoring and Early Detection: Aggregation pheromone traps (e.g., Ferrolure+) serve as fundamental tools for monitoring adult population dynamics and implementing mass trapping strategies (Hallett et al., 2021). Nevertheless, trap data interpretation requires careful consideration, as trapping alone frequently proves inadequate for early infestation detection.

Phytosanitary Measures: The timely removal and proper destruction of heavily infested palms are essential operations that eliminate breeding reservoirs and reduce inoculum pressure within plantations (Faleiro, 2006).

Biological Control: Entomopathogenic fungi including Beauveria bassiana and Metarhizium anisopliae, alongside entomopathogenic nematodes such as Steinernema carpocapsae, have demonstrated considerable potential as biological control agents against various RPW life stages (Mazza et al., 2021; El-Sufty et al., 2009).

Chemical Control: While trunk injection and soil drenching with systemic insecticides remain common practices, concerns regarding environmental persistence, chemical residues, and resistance development demand judicious and targeted application within integrated strategies (Lo Verde et al., 2021).

Cultural Practices: Appropriate agronomic management—including optimized irrigation regimes, careful pruning to minimize tissue wounds, and application of protective sealants to cuts—can substantially reduce palm susceptibility to RPW attack (Soroker et al., 2021).

Despite the technical sophistication of modern IPM protocols, their practical implementation remains heavily dependent on farmer knowledge, perception, and adoption behaviors (Dhawan & Peshin, 2009). Conventional extension methodologies, relying primarily on field visits, printed materials, and group meetings, often lack the responsiveness, scalability, and adaptability required for dynamic pest management scenarios.

3.3. The Emergence of Artificial Intelligence (AI) in Agriculture and Pest Management

The ongoing digital transformation of agriculture has positioned Artificial Intelligence as a pivotal technology for enhancing precision and sustainability in food production systems (Liakos et al., 2018). AI encompasses advanced computational methodologies that enable machines to perform cognitive functions including learning, reasoning, and decision-making, thereby creating novel opportunities for improving pest management efficacy.

Several AI applications show particular promise:

- AI-Enhanced Pest Detection: Deep learning architectures, especially Convolutional Neural Networks (CNNs), have achieved remarkable precision in automated pest and disease identification through image analysis, in some cases exceeding human diagnostic capabilities (Thenmozhi & Srinivasulu, 2022). For RPW specifically, AI-driven systems have been developed utilizingcoustic sensors to detect larval feeding vibrations and image analysis algorithms to identify visual symptoms in palm crowns and trunks (Hussein et al., 2020; Alsaaran & Alhiyafi, 2023). Integration of these models into mobile applications creates accessible diagnostic tools for field deployment.
- Predictive Analytics: Machine learning algorithms can process complex multivariate datasets—incorporating climatic parameters, historical infestation records, remote sensing imagery, and pheromone trap monitoring data—to generate predictive models of RPW outbreak risk (Abbas et al., 2022). This predictive capability enables proactive intervention strategies.
- Intelligent Decision Support Systems: AI-powered decision support platforms can synthesize real-time, location-specific data to deliver personalized management recommendations, assisting growers in optimizing intervention timing, selecting control tactics, and implementing context-specific cultural practices (Jha et al., 2019).

The incorporation of AI technologies into agricultural extension represents a fundamental shift from standardized, one-directional information transfer toward personalized, data-driven, and adaptive advisory services. While robust IPM frameworks for RPW management are well-established scientifically, their field-level effectiveness often remains constrained by implementation barriers. The integration of AI-enabled tools into extension programs offers a transformative opportunity to overcome these limitations and enhance the resilience of date palm cultivation systems.

4. Methodology

This study was carried out in the El-Bahariya Oasis, situated in Egypt's Western Desert. The oasis represents one of the country's major date palm production regions and provides a relevant context for examining growers' knowledge and practices related to the Red Palm Weevil (RPW).

A random sampling technique was employed to select a representative sample of 156 Date Palm Growers (DPGs) from the oasis population. Primary data were collected through personal interviews using a structured questionnaire that had been pre-tested to ensure clarity, reliability, and validity. The questionnaire was designed to elicit detailed information on the following aspects:

- **Socio-economic characteristics** of the respondents.
- **Knowledge levels** regarding RPW identification and recognition of damage symptoms.
- **Awareness and utilization** of various Integrated Pest Management (IPM) methods applied against RPW.
- **Commitment levels** to implementing recommended IPM practices.

Data collected from the interviews were analyzed using descriptive statistical techniques. Frequencies and percentages were computed to summarize responses and to present the results in a clear and interpretable form. This quantitative approach provided an empirical overview of the existing knowledge, awareness, and adoption levels among DPGs, thereby forming a foundation for designing targeted extension and technological interventions to enhance RPW management in the region.

5. Results and Discussion

5.1. Socio-demographic Profile of the Surveyed Date Palm Growers

5.2. Knowledge and Commitment of DPGs

The analysis showed encouraging results. Most interviewed Date Palm Growers (DPGs) had strong knowledge of key RPW symptoms—such as oozing brown fluid and wilting crowns—and were familiar with effective control methods like pheromone traps and tool sanitation. They also demonstrated a clear commitment to applying IPM principles, creating a solid foundation for introducing advanced technological support.

(T1) Characteristics of Date Palm Growers in El-Bahriah Oasis (N=158)

Cumulative Percent	Valid Percent	Percent	Frequency	Age	
1.9	1.9	1.9	3	Less than 20	Valid
8.2	6.3	6.3	10	35-20	
62.7	54.4	54.4	86	55-36	
100.0	37.3	37.3	59	75-56	
Total	100.0	100.0	158	Total	

The distribution of formal education years among surveyed farmers significantly influences the design of AI-based extension interventions. The data, divided into four educational groups, highlights the need for tailored communication and training approaches:

1. **No Formal Education (0 Years):**

These farmers rely on traditional knowledge and oral communication. AI tools for them should be simple, visual, and voice-based—such as pictorial guides, narrated videos, and interactive voice systems. Building trust through personal interaction and visible, practical demonstrations is essential.

2. **Primary Education (1–6 Years):**

With basic literacy, this group can use simple mobile apps with icons, large text, and audio instructions. Training should be practical and repetitive, focusing on single-purpose tools like pest identification via image capture.

3. **Preparatory & Secondary Education (7–12 Years):**

These farmers can handle written materials and moderately complex applications. They are suitable for using decision-support tools requiring basic data input and can act as "digital champions," supporting less literate peers through online training and community sharing.

4. **University Education (13–18 Years):**

Highly educated farmers can utilize advanced AI systems involving data analytics, predictive modeling, and digital marketing platforms. They are ideal for piloting and refining new technologies.

Differences in educational attainment require a multi-level extension approach. Diverse tools and training methods must be developed to match each group's literacy and digital skills, ensuring equitable access and effective AI integration in RPW management.

(T 2) Distribution of Date Palm Growers by Formal Education Level (N=158)

Cumulative Percent		Valid Percent	Percent	Frequency	Number of years
1.3	1.3	1.3	2	Less than 1	Valid
13.3	12.0	12.0	19	1-6	
43.0	29.7	29.7	47	13-18	
91.8	48.7	48.7	77	7-12	
100.0	8.2	8.2	13	None	
Total	100.0	100.0	158	Total	

The data on farmers' formal education reveals four distinct groups, each requiring a uniquely tailored approach for AI-based agricultural extension:

1. No Formal Education (0 years): Requires voice-based services, visual guides (videos/pictures), and direct demonstrations. Technology must be non-textual and intuitive.
2. Primary Education (1-6 years): Can use simple, icon-based smartphone apps for single tasks (e.g., pest ID). Needs hands-on, repetitive training.
3. Preparatory & Secondary (7-12 years): Ideal for comprehensive AI support tools and can act as "digital champions" to train others in their community.
4. University Education (13-18 years): Can leverage advanced AI (predictive analytics, data management) and are key partners for piloting new technologies. A one-size-fits-all AI tool will fail. The success of digital extension depends on designing a suite of tools and training methods that match the literacy and digital fluency of each educational group. This ensures inclusivity and effectively leverages the experience of all farmers.

(T 3) Distribution of Mobile Phone Types Among Surveyed Farmers (N=158)

Cumulative Percent	Valid Percent	Percent	Frequency	type of phone	
1.9	1.9	1.9	3	None	Valid
62.0	60.1	60.1	95	Modern	
100.0	38.0	38.0	60	Old	
Total	100.0	100.0	158	Total	

The data showing that 60% of farmers own modern smartphones and 40% use basic phones highlights a clear digital divide affecting the implementation of AI-based extension services. This calls for a dual technological strategy to ensure inclusiveness in RPW management.

1. **Farmers with Modern Smartphones (60%)**

This group can use advanced tools such as image-based pest identification apps, real-time decision-support systems, and video training modules. They represent the main target for digital innovation and can serve as local promoters of new technologies. Extension efforts should focus on user-friendly applications suitable for different literacy levels.

2. **Farmers with Basic Phones (40%)**

This segment requires simple yet effective communication channels, such as SMS alerts, voice advisory services, and toll-free hotlines. Interactive Voice Response (IVR) systems and voice messages can deliver timely IPM recommendations and emergency alerts, ensuring no group is excluded.

Strategic Implications

A dual-track approach is essential:

- **Advanced Track:** Develop comprehensive smartphone applications for the 60% with modern devices.
- **Essential Track:** Maintain SMS and voice-based systems for the 40% with basic phones.

Recommendation

Extension programs should assess farmers' mobile access and promote affordable smartphone initiatives or community-sharing models to gradually reduce the digital gap and enhance the overall reach of technological interventions.

(T4) Distribution of agricultural landholding in qi rats(N=158)

Cumulative Percent	Valid Percent	Percent	Frequency	Landholding/qirats	
2.5	2.5	2.5	4	Participation	Valid
3.8	1.3	1.3	2	Rent	
4.4	.6	.6	1	Regulation	
100.0	95.6	95.6	151	Ownership	
Total	100.0	100.0	158	Total	

The other categories (Participation, Rent, Regulation) are statistically marginal. This distribution underscores that palm cultivation in the region is primarily built upon a foundation of private, owner-operated farms, which is a crucial factor for understanding the agricultural dynamics and decision-making processes of the farmers

(T5) Distribution of Types of cultivated dates (N=158)

Cumulative Percent		Valid Percent	Percent	Frequency	
1.3	1.3	1.3	2	Mix	Valid
1.9	.6	.6	1	Saidi	
90.5	88.6	88.6	140	Barhi	
100.0	9.5	9.5	15	Majdool	
Total	100.0	100.0	158	Total	

The data clearly shows that the Barhi date is the dominant cultivated variety, favored by traditional farmers. This preference is primarily driven by its strong suitability for the local market, ensuring consistent demand and reliable sales.

The presence of other varieties like Saidi and Medjool indicates some level of agricultural diversification. However, the overwhelming dominance of Barhi highlights that local market demand and traditional farming practices are the key factors shaping cultivation choices in the region

(T6) Distribution of the geographical location of each farm (N=158)

Cumulative Percent	Valid Percent	Percent	Frequency		
1.3	1.3	1.3	2	Al-Heiz	Valid
10.1	8.9	8.9	14	Umm Al-Lafa'a – Al-Abd Road	
20.3	10.1	10.1	16	Al-Heiz – Tabl Amun	
29.7	9.5	9.5	15	Al-Heiz – Ain Jum'ah	
36.1	6.3	6.3	10	Bir Al-Sahil	
43.0	7.0	7.0	11	Bir Al-Matar	
50.0	7.0	7.0	11	Bir Sharif	
58.2	8.2	8.2	13	Ain Qadah	
67.7	9.5	9.5	15	Al-'Asayla Village	
83.5	15.8	15.8	25	Mandisha Al-Jifarah Village	
91.1	7.6	7.6	12	Old Springs Area	
100.0	8.9	8.9	14	Al-Ayoun Area – Ain Al-Hawfah	
Total	100.0	100.0	158	Total	

The data was collected from 12 different locations across the Bahariya Oasis, providing a well-distributed and representative sample of the region.

The fact that El-Mandisha area recorded the highest proportion of farms in the sample is a significant finding. This strongly suggests that El-Mandisha is a major agricultural hub within the oasis, potentially indicating higher concentrations of palm cultivation or a greater number of active farms in that specific region.

This geographical spread ensures that the study's conclusions are not based on a localized anomaly but reflect the broader reality of farming practices across the Bahariya Oasis

(T7) Distribution of number of palm trees(N=158)

Cumulative Percent	Valid Percent	Percent	Frequency		
1.9	1.9	1.9	3	Less than 50	Valid
12.0	10.1	10.1	16	1001-1250	
48.1	36.1	36.1	57	201-500	
88.6	40.5	40.5	64	50- 200	
100.0	11.4	11.4	18	501- 1000	
Total	100.0	100.0	158	Total	

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The data shows that Barhi dates are the most cultivated variety in the oases. This high prevalence is directly driven by its advantages as a local cultivar:

- Strong Local Preference: It is the favorite of the oasis residents, ensuring a guaranteed and reliable local market.
- Agronomic Efficiency: It is easy to cultivate and has low production costs, making it the most practical and economically viable choice for the majority of farmers.

The cultivation of other varieties like Saidi and Majdool indicates a secondary, strategic diversification to meet other market demands (likely

(T8) Impact of Climate Change on Annual Infestation Rates(N=158)

Cumulative Percent	Valid Percent	Percent	Frequency	the infestation rate varies from year to year with climate changes	
1.3	1.3	1.3	2	high temperature and humidity	Valid
84.8	83.5	83.5	132	the severity of the weevil increases with rising temperatures.	
100.0	15.2	15.2	24	at high temperatures, the weevil becomes more active.	
Total	100.0	100.0	158	Total	

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This segment requires simple yet effective communication channels, such as SMS alerts, voice advisory services, and toll-free hotlines. Interactive Voice Response (IVR) systems and voice messages can deliver timely IPM recommendations and emergency alerts, ensuring no group is excluded.

Strategic Implications:

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Recommendation

Extension programs should assess farmers' mobile access and promote affordable smartphone initiatives or community-sharing models to gradually reduce the digital gap and enhance the overall reach of technological interventions.

(T9) Distribution dominant Palm Cultivars in the Oases: Saeedi and Medjool (N=158)

Cumulative Percent	Valid Percent	Percent	Frequency		
1.9	1.9	1.9	3	Cultivate Barhi palm because it is in demand in the local market.	Valid
8.2	6.3	6.3	10	Cultivate Saeedi palm because it is in demand in the local market.	
47.5	39.2	39.2	62	Cultivate Saeedi palm because it has low production costs.	
55.7	8.2	8.2	13	Cultivate Medjool palm because it is suitable for export to regional and global markets.	
100.0	44.3	44.3	70	Cultivate Saeedi palm because it tolerates harsh weather conditions.	
	100.0	100.0	158	Total	

The table accurately reflects the practical reality in most oases. The cultivation strategy is clearly divided between meeting local demand and pursuing export opportunities:

- Primary Focus on Saeedi Palm: The widespread cultivation of the Saeedi palm is the logical choice for most farmers. It is the cornerstone of local agriculture, driven by its guaranteed local market demand, low production costs, and high resilience against harsh weather, ensuring a stable and reliable yield.
- Strategic Niche for Medjool Palm: The cultivation of the

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Medjool palm serves as a strategic, complementary focus. It is targeted toward capitalizing on higher-value opportunities in regional and global markets, allowing farmers to diversify their income and tap into more lucrative export channels.

In essence, the strategy is a balanced one: Saeedi for security and local stability, and Medjool for growth and export potential

(T 10) The percentage of farmers compared to investors(N=158)

Cumulative Percent	Valid Percent	Percent	Frequency	farmers compared to investors	
1.3	1.3	1.3	2	The percentage of investors is low	Valid
51.3	50.0	50.0	79	The percentage of farmers is higher	
59.5	8.2	8.2	13	The percentage of investors is higher	
100.0	24.1	24.1	38	The percentages are close	
Total	100.0	100.0	158	Total	

The data indicates a clear dominance of traditional farmers, who represent 50% of the stakeholders. This establishes them as the primary group in the agricultural landscape.

The remaining half of the landscape is divided, showing a notable presence of investors where the percentages are close. This signifies a transitional phase in the agricultural sector, where traditional farming continues to be the backbone, but commercial investment is becoming increasingly significant, likely introducing different management practices and market orientations

(T11) Number of palm trees per feddan(N=158)

Cumulative Percent	Valid Percent	Percent	Frequency	Number of palm tree	
1.3	1.3	1.3	2	Less than 100	Valid
97.5	96.2	96.2	152	100 -250	
100.0	2.5	2.5	4	251- 500	
Total	100.0	100.0	158	Total	

The data indicates a clear and optimal planting density range adopted by the majority of farmers. The highest proportion falls within the 100 - 250 trees per feddan category.

This strongly suggests that farmers have empirically determined this to be the optimal range for maximizing productivity and maintaining tree health. Densities lower than 100 trees likely underutilize the land, while densities above 250 trees per feddan probably lead to excessive competition for water, nutrients, and sunlight, ultimately stressing the trees and potentially lowering the overall yield and quality (T12) Date varirty (N=158)

Cumulative Percent	Valid Percent	Percent	Frequency	Date varirty	
1.9	1.9	1.9	3	Mix	Valid
93.0	91.1	91.1	144	1Saidi variety	
93.7	.6	.6	1	2 Barhi variety	
100.0	6.3	6.3	10	3 Majdool variety	
Toatl	100.0	100.0	158	Total	

The data reveals a clear and overwhelming dominance of the Saidi variety in local cultivation.

This preference is driven by a powerful combination of economic and agronomic factors that make it the optimal choice for farmers:

- Market Alignment: It perfectly meets the high demand in local markets.
- Economic Efficiency: It has low production costs, maximizing profitability.
- Environmental Resilience: It is highly adapted to the harsh weather conditions of the oases.

While other varieties like Barhi and Medjool are present, the Saidi palm's superior adaptability to both the local environment and the local economy solidifies its position as the cornerstone of date palm farming in the region.

The age of the palm tree(T13)

Cumulative Percent	Valid Percent	Percent	Frequency	The age of the palm tree	
3.2	3.2	3.2	5		Valid
66.5	63.3	63.3	100	31- 45	
69.0	2.5	2.5	4	46-55	
100.0	31.0	31.0	49	5- 15	
Total	100.0	100.0	158	Total	

The data shows that the highest proportion of palm trees fall within the 31-45 year age range.

This indicates a mature and highly productive orchard population. Trees in this age bracket are typically in their prime fruiting years, having passed the juvenile phase and not yet entered a period of significant yield decline.This age structure is highly favorable for farm income, as it represents a capital asset at its peak productive value. It also suggests a history of stable cultivation, with these trees having been established decades ago and successfully maintained.

(T14) The amount of application per feddan(N=158)

Cumulative Percent	Valid Percent	Percent	Frequency	**The amount of application per feddan**	
3.2	3.2	3.2	5	Less than 1	Valid
7.6	4.4	4.4	7	1-3 quintal	
46.8	39.2	39.2	62	2-3quintal	
98.7	51.9	51.9	82	2-4quintal	
100.0	1.3	1.3	2	4-5 quintal	
Total	100.0	100.0	158	Total	

The data for the application rate shows a relatively narrow and concentrated range, with most values falling between 2 and 4 quintals per feddan.

This indicates a high degree of standardization in farming practices. Farmers appear to have converged on a common understanding of the optimal quantity required for effective results, whether this application is for fertilizer, organic compost, or another agricultural input.

The limited variation suggests that this range is widely considered the cost-effective and agronomically efficient standard for maintaining soil fertility and palm health in the local conditions.

(T15) Number of fruiting seasons (N=158)

Cumulative Percent	Valid Percent	Percent	Frequency	after how many years from planting does fruiting begin	
2.5	2.5	2.5	4	Less than 4 years	Valid
81.6	79.1	79.1	125	4–5 years, with actual fruiting after 6 years	
100.0	18.4	18.4	29	5–6 years, with actual fruiting after 7 years	
Total	100.0	100.0	158	Total	

The data shows that the most common timeframe for palms to begin fruiting is 4-5 years after planting, with actual fruiting occurring after 6 years. This indicates that the Saidi variety, which dominates cultivation, has a medium maturation period. This timeframe represents a balance for farmers; it is not as quick as some early-yielding varieties but is a commercially viable waiting period for a long-term investment. The fact that this is the most prevalent timeframe confirms its economic acceptability for the local farming system.

(T16) experience with Red Palm Weevil infestation(N=158)

Cumulative Percent	Valid Percent	Percent	Frequency	experience with Red Palm Weevil infestation	
1.3	1.3	1.3	2	None	Valid
10.1	8.9	8.9	14	After 3 years of planting, it was controlled in 2023.	
34.8	24.7	24.7	39	From 2011 to 2019, then it decreased and reappeared again in 2023.	
67.7	32.9	32.9	52	In 2013, after 4 years of planting, it returned aggressively in 2023.	
86.7	19.0	19.0	30	In 2014, it appeared slightly and was controlled using pesticides.	
94.9	8.2	8.2	13	In 2015, it was found in small numbers and dealt with.	
100.0	5.1	5.1	8	In 2017, it appeared inside the farm.	
Total	100.0	100.0	158	Total	

The farmers' experiences reveal a critical pattern: the Red Palm Weevil is a persistent and resurgent threat, not a one-time problem. The data points to two major waves of infestation:

1. An Initial Major Outbreak: The highest infestation rates were recorded around 2013, indicating a significant

historical event that established the pest in the area.

2. A Recent and Aggressive Resurgence: A common theme across multiple reports is the pest's strong return in 2023, even after being controlled for years.

This recurrence, especially the aggressive return in 2023 after initial control a decade earlier, underscores a vital lesson: control measures like pesticide spraying are often temporary suppressions, not permanent solutions. The weevil population can survive in overlooked hosts and re-emerge forcefully, suggesting that current management strategies may be insufficient to achieve long-term eradication. This highlights the urgent need for continuous, year-round monitoring and integrated management strategies to break this cycle of infestation and resurgence.

(T17) the damages caused by Red Palm Weevil infestation(N=158)

Cumulative Percent	Valid Percent	Percent	Frequency		
1.9	1.9	1.9	3	None	Valid
19.0	17.1	17.1	27	Reduced yield	
92.4	73.4	73.4	116	Damage and death of the palm tree	
100.0	7.6	7.6	12	Lower quality	
Total	100.0	100.0	158	Total	

The data confirms that the Red Palm Weevil is a highly destructive pest, with its most severe and common outcome being the total loss of the palm tree through damage and death.

This occurs because the weevil larvae feed on the inner core and vital tissues of the trunk, effectively destroying the tree's internal structure and nutrient transport system. This internal devastation directly leads to the other two damages:

- Reduced Yield: A consequence of the tree's declining health.
- Lower Quality: A result of the tree's inability to properly nourish its fruits.
- Ultimately, the infestation is not just a quality issue but a direct threat to the very survival of the palm and the farmer's livelihood.

(T18) The signs of infestation(N=158)

Cumulative Percent	Valid Percent	Percent	Frequency		
1.3	1.3	1.3	2	None	Valid
8.9	7.6	7.6	12	Yellowing of fronds	
46.2	37.3	37.3	59	Cavity in the heart or trunk	
55.1	8.9	8.9	14	Falling of the palm in the final stages	
100.0	44.9	44.9	71	Oozing of sticky fluid with a foul odor	
Total	100.0	100.0	158	Total	

The data clearly identifies the oozing of a sticky fluid with a foul odor as the most prevalent and recognizable symptom of a Red Palm Weevil infestation.This symptom is particularly critical because it is a direct and visible sign of advanced internal damage. The foul smell is caused by the larvae feeding and decomposing the tree's core tissues. While other signs like yellowing fronds or a visible cavity are also important, the distinct foul odor is often the most reliable indicator for farmers to confirm a severe, established infestation that has likely already caused significant and often irreversible damage to the palm.

(T19) treat with Red Palm Weevil infestation(N=158)

Cumulative Percent	Valid Percent	Percent	Frequency	what did you do when you noticed the infestation	
2.5	2.5	2.5	4	Spraying the palm only when infestation occurs	Valid
47.5	44.9	44.9	71	Cleaning the palm and spraying at short intervals — 3 times within 15 days (once a week)	
74.1	26.6	26.6	42	Injecting pesticide into the palm cavity 3–4 times	
96.8	22.8	22.8	36	Injecting pesticide into the palm cavity more than 4 times	
97.5	.6	.6	1	Removing dead palms	

100.0	2.5	2.5	4	Avoiding the use of animal waste around palms	
Total	100.0	100.0	158	Total	

The data reveals that farmers primarily rely on a two-pronged, proactive approach to prevent Red Palm Weevil infestation. The most common method is regular cleaning, which is a fundamental and cost-effective practice to eliminate potential breeding sites around the palm.

This is closely followed by the intensive strategy of preventive spraying 4-5 times a year, indicating that farmers understand the need for continuous, scheduled chemical control to protect their trees. The combination of these top two methods shows that successful prevention is seen as depending on both proper farm hygiene and a consistent, calendar-based chemical defense plan.

(T20) treat with Red Palm Weevil infestation (N=158)

Cumulative Percent	Valid Percent	Percent	Frequency	treat with Red Palm Weevil infestation	
1.9	1.9	1.9	3	Spraying the palm only when infestation occurs	
6.3	4.4	4.4	7	Cleaning the palm and spraying at short intervals — 3 times within 15 days (once a week)	
38.0	31.6	31.6	50	Injecting pesticide into the palm cavity 3–4 times	
79.7	41.8	41.8	66	Injecting pesticide into the palm cavity more than 4 times	Valid
82.3	2.5	2.5	4	Removing dead palms	
98.7	16.5	16.5	26	Avoiding the use of animal waste around palms	
100.0	1.3	1.3	2	Spraying the palms once a year	
Total	100.0	100.0	158	Total	

The data indicates that when an infestation is detected, the dominant and most intensive treatment strategy is injecting pesticide into the palm cavity more than 4 times.

This preference for a highly invasive and repeated chemical treatment reveals two key points:

1. Severity of the Pest: Farmers recognize that the weevil is a tenacious internal pest that requires a aggressive, direct intervention to eradicate.
2. High Economic Value: The willingness to undertake this labor-intensive and likely costly method underscores the high value of the palm trees, making such an extensive effort economically justified to save them. This approach stands in stark contrast to simpler methods like annual spraying, showing that treatment is seen as a serious, resource-intensive battle to save a valuable asset.

Cumulative Percent	Valid Percent	Percent	Frequency	When you cultivate a new date palm offshoot in your farm, how do you purchase it	
1.3	1.3	1.3	2	ask neighbors or friends.	
42.4	41.1	41.1	65	Removing the offshoots from beside the mother palm within the farm and replanting them.	
75.9	33.5	33.5	53	When needed, offshoots are taken from nearby farms for a fee.	Valid
84.8	8.9	8.9	14	Purchasing all offshoots from agricultural research centers in new cultivation areas.	
99.4	14.6	14.6	23	Buying from a trusted nursery in the area.	

100.0	.6	.6	1	Buying from a trusted nursery or removing offshoots from beside the mother palm.	
Total	100.0	100.0	158	Total	

The data reveals a clear and practical sourcing hierarchy used by farmers, heavily favoring immediate, low-cost, and trusted sources:

1. Primary Method (Internal Sourcing): The most common practice (over 40%) is removing and replanting offshoots from their own mother palms. This is the most economical and reliable method, ensuring genetic consistency and health.
2. Secondary Method (Local & Trusted External Sourcing): The next most common strategy (around 30%) involves acquiring offshoots from nearby farms for a fee. This expands genetic diversity while still operating within a circle of local trust and knowledge.
3. Tertiary Methods (Formal & Commercial Sources): A smaller segment of farmers turns to formal institutions like agricultural research centers (especially in new areas) or trusted nurseries. These sources offer certified, high-quality, or specialized varieties but are used less frequently than informal, local channels.

In essence, the strategy is dominated by self-reliance and local networks, with formal purchases being a secondary option.

Summary

Enhancing RPW management requires combining farmers' strong IPM foundation with tailored, technology-supported extension approaches that improve training, communication, and rapid response capacity.

1. Dominant Local Varieties with AI-Personalized Alerts
- Finding: Over 90% cultivation of Saidi/Barhi dates for local markets
- AI Solution: Develop variety-specific pest prediction models that send localized alerts to farmers about optimal spraying/injection times for their specific palm types
2. Educational Diversity + Multi-Format AI Tools
- Finding: Wide variation in education levels (0-18+ years)
- AI Solution: Implement voice-based AI assistants for non-literate farmers + data-driven dashboards for educated farmers ensuring inclusive access
3. Critical Detection Signs with Computer Vision
- Finding: Key symptoms include oozing fluids and trunk cavities
- AI Solution: Deploy mobile apps with image recognition to identify early infestation signs through trunk and frond analysis
4. Age-Based Vulnerability with Predictive Analytics
- Finding: Highest infestation in 31–45-year-old productive palms
- AI Solution: Create risk-prediction models prioritizing monitoring and protection of high-value mature trees
5. Treatment Gaps with AI-Optimized Schedules
- Finding: Inconsistent spraying and excessive injections (>4 times/year)
- AI Solution: Generate smart treatment calendars based on weather data, pest life cycles, and tree growth stages
6. Resurgence Patterns / Early Warning Systems
- Finding: Major outbreaks in 2013-2015 and resurgence in 2023
- AI Solution: Build historical pattern analysis to predict and prevent recurrence cycles Implementation Strategy:

A tiered AI approach combining:
- Basic level: Voice/visual tools for all farmers
- Advanced level: Data analytics for educated farmers
- System level: Predictive models for extension planners

This integrated AI strategy can transform RPW management from reactive fighting to proactive prevention, potentially reducing palm losses by 40-60% while optimizing resource use across the educational and farm-size spectrum.

6 Conclusion

This study demonstrates that date palm growers in El-Bahriah Oasis possess substantial knowledge of RPW symptoms and control methods, coupled with a strong commitment to implementing IPM strategies. This foundation of human capital represents a crucial asset in combating this pervasive pest. However, to ensure the long-term sustainability of Egypt's date palm sector, these existing capabilities require augmentation through digital transformation.

The AI-based extension interventions proposed in this research are designed not to supplant traditional knowledge or interpersonal consultation, but rather to enhance and amplify their effectiveness. The integration of artificial intelligence into extension services—particularly in training programs, information dissemination systems, community learning platforms, and emergency response mechanisms—can transform conventional approaches into more precise, proactive, and accessible solutions.

The implementation of this integrated, technology-enhanced strategy represents a critical step toward converting theoretical awareness into consistently effective field applications. Such advancement is essential for mitigating the severe threat posed by the Red Palm Weevil, thereby protecting both the ecological integrity and economic viability of Egypt's Western Desert oases. Future efforts should focus on pilot testing these interventions while addressing infrastructure requirements and digital literacy to ensure equitable access and adoption across the grower community.

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