



وزارة البيئة والمياه والزراعة
Ministry of Environment Water & Agriculture

Saudi Arabia
Centre for the
Fourth Industrial
Revolution

Establishment of Tech-Enabled Pest Management Framework, the Case of the Red Palm Weevil

Technical Report

January 2025



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List of Acronyms

4IR: Fourth Industrial Revolution

C4IR Saudi Arabia: Centre for the Fourth Industrial Revolution, affiliated with the World Economic Forum

IoT: Internet of Things

KAUST: King Abdullah University for Science and Technology

KFU: King Faisal University

KSA: Kingdom of Saudi Arabia

KSU: King Saud University

MEWA: Ministry of Environment Water and Agriculture

NCPD: National Center for Palms and Dates

NTP: National Transformation Program

RPW: Red Palm Weevil

TRL: Technology Readiness Level

WEQAA Center: National Center for the Prevention and Control of Plant Pests and Animal Diseases

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Foreword



Deputy Minister of Research & Innovation for Ministry of Environment, Water, and Agriculture

Dr. Abdulaziz Almalik

“As the Deputy Minister of Research & Innovation at MEWA, I am proud to emphasize our unwavering commitment to the Kingdom's palm and date sector. This sector not only represents a key part of our cultural heritage but also plays a vital role in supporting food security and economic sustainability. Our approach to combating the Red Palm Weevil infestation is centered on fostering innovative solutions, engaging regional and global experts, and leveraging advanced technologies. By adopting a comprehensive, integrated strategy, we are taking significant steps toward ensuring the long-term health of our palm farms, preserving a crucial pillar of Saudi Arabia's agricultural landscape.”



Managing Director of the Center for the Fourth Industrial Revolution Saudi Arabia, World Economic Forum Affiliate Centre

Dr. Basma AlBuhairan

“In the era of rapid technological advancement, agriculture faces pressing ecological challenges that demand innovative solutions. Saudi Arabia, a global leader in date production, recognizes the critical importance of food security and agricultural economic viability in alignment with its Vision 2030 objectives. The Red Palm Weevil infestation has emerged as a significant threat to the Kingdom's date palm industry, necessitating a coordinated national response. This report presents a comprehensive roadmap for implementing cutting-edge technologies and associated regulatory frameworks to effectively combat the Red Palm Weevil. The focus is on sustainable pest management practices that not only address the immediate threat, but also ensure the long-term resilience of Saudi Arabia's date palm sector.”

Executive Summary

The date palm holds a significant heritage, historical, and religious place for Saudi Arabia. For thousands of years, it has been a symbol of generosity and sustenance, serving as a source of livelihood and stability. The palm is mentioned in the Qur'an and the teachings of the Prophet Muhammad, peace be upon him, reinforcing its importance in Islam as a symbol of blessing and goodness, with dates recommended for their health benefits. Additionally, the date palm is an essential part of Saudi national identity, representing resilience and adaptability to the natural environment, with the Kingdom being the second-largest global producer of dates in 2022.

To protect and enhance this vital sector, the Saudi government has implemented various initiatives that leverage innovative solutions to further enhance date palm cultivation, with a particular focus on combating threats such as the Red Palm Weevil (RPW). Programs led by the Ministry of Environment, Water, and Agriculture (MEWA) and organizations like the National Center for the Prevention and Control of Plant Pests and Animal Diseases (WEQAA Center) focus on mitigating RPW through both traditional and technological methods that align with the Kingdom of Saudi Arabia's (KSA) Vision 2030.

In response to the Kingdom's strong support for the agricultural sector and commitment to leveraging innovative solutions, efforts have reduced infestation rates from 0.98% in 2016 to 0.26% in 2023 for small farms (less than 500 trees), but opportunities to extend mitigation efforts remain for larger farms where infestations are not yet effectively controlled. This underscores the need for broader technology deployment to provide a comprehensive RPW management solution. A coalition involving MEWA, the Centre for the Fourth Industrial Revolution Saudi Arabia (C4IR Saudi Arabia), National Center for Palms and Dates (NCPD), WEQAA Center, and leading national academic institutions have launched an effort to develop and implement an integrated technological solution to control RPW infestation nationwide.

The RPW Infestation Solutions Project is structured into two phases. In the first phase, which has concluded, a sector assessment was conducted, identifying potential technologies refined to 15 top choices based on readiness, impact, and strategic alignment. In the second phase, the focus will be on four main workstreams: Research and Development, Technology Deployment, Commercial Deployment, and Systemic Enablement, all aimed at facilitating successful RPW mitigation technologies and strengthening research capabilities throughout the Kingdom.

This technical report provides a progress update on the project's ongoing efforts to achieve its main goal: reducing RPW infestation and protecting the Date Palm sector. The report aims to propose the need to develop a comprehensive approach that utilizes advanced technological solutions, especially in biotechnology, while fostering a collaborative ecosystem through

effective governance for RPW management. Additionally, it outlines a framework to tackle the challenges of adopting agricultural technologies more broadly in Saudi Arabia.

The RPW Infestation Solutions Project charts a path for advanced technological integration into the palm and date industry to enhance RPW management and secure the industry's future. The forthcoming steps include implementing these programs and evaluating their effects to maintain successful RPW management in KSA. Moreover, establishing robust governance structures focusing on regulatory compliance, data protection, and ethical standards is essential to align technology deployment with national policies and sustainability objectives.

1. Date Palm Sector and RPW Infestation in KSA

1.1. KSA Agriculture: Overview and Objectives

KSA's agricultural sector plays a crucial role in supporting the country's economic sustainability and ensuring its food security. The National Agriculture Strategy sets forth the objectives for the agriculture sector in the Kingdom, and includes innovation and leadership as one of its six pillars. Moreover, and as part of KSA's Vision 2030, the Kingdom has launched multiple initiatives related to the theme of "ensuring sustainability of vital resources" as part of its National Transformation Program (NTP) 2021-2025. The theme includes strategic objectives such as, "ensuring development and food security," "safeguarding the environment from natural threats," and "protecting and rehabilitating natural landscapes." These objectives are achieved through various initiatives led by multiple entities, including MEWA.

The NTP includes many initiatives within it to help attain its objectives in the food and agriculture sector. Among the initiatives led by MEWA under the NTP 2021-2025 is the "Development of an Integrated Management System for Controlling Plants Epidemics." This initiative focuses on establishing policies, regulations, and action plans that effectively manage plant diseases and pests. This ensures the sustained productivity of the Kingdom's agricultural sector.

Another initiative by MEWA and under the NTP is the "Program for Prevention and Control of the Red Palm Weevil, which focuses on protecting the palm sector. This initiative significantly contributes to protecting palm trees by implementing advanced technological solutions, particularly for combating RPW infestation.

1.2. Palm and Date Industry: Significance and Targets

The Kingdom ranks among the world's top producers of dates, producing 1.9 million tons in 2023 according to the General Statistics Authority. The country has an estimated 36 million date palm trees, 67% of which are located in three key regions: Qassim, Madinah, and Riyadh. The industry's importance is underscored by its contribution to the national economy, food security, and cultural heritage.

Given its significance, Vision 2030 outlines specific targets for the palm and date industry, aiming to enhance its productivity and sustainability. MEWA's strategy aligns with these targets, emphasizing the protection and development of the sector through initiatives led by

WEQAA Center, the MEWA-affiliated center tasked with managing plant and animal diseases in KSA. Among WEQAA Center's key initiatives are:

- **Integrated Management System for Controlling Plant Epidemics:** This initiative focuses on developing policies, regulations, and action plans to control plant diseases and pests. It involves establishing laboratories, supporting stakeholders, and providing critical information to facilitate technology adoption and enhance product development, ultimately aiming to safeguard and improve agricultural production.
- **Program for Prevention and Control of RPW:** This program aims to curb the spread of RPW by raising awareness among farming communities and deploying advanced technologies to address infestations effectively.

1.3. Technology in Agriculture: Enhancement Opportunity

Saudi Arabia's agricultural sector currently combines traditional farming practices with the integration of modern technological advancements. Even though traditional practices have been the backbone of the sector for generations, critical challenges like climate change, population growth, and widespread epidemics have made these classic methods less effective in addressing urgent issues. More robust solutions are essential to achieve agricultural objectives, and these can be optimized by adopting modern technology.

Central to this effort is MEWA's goal to improve the palm and date industry in KSA, which includes controlling infestations through the integration of cutting-edge tools and practices. To achieve this, MEWA's Research and Innovation Deputyship developed a comprehensive RPW control program that encompasses supervising the deployment of technologies and conducting applied research experiments on technologically innovative solutions.

1.4. RPW Context

1.4.1. RPW Local Invasiveness

The mitigation of the spread of RPW in KSA offers an opportunity to further strengthen the date palm sector. First detected in the Eastern Region in 1987, RPW's movement and high reproductive rate enabled it to expand into other areas. It then spread such that by 1989, it had reached Riyadh and Tabuk, and by 1992, it had spread to Makkah. The infestation continued, reaching Hail, Madinah, and Baha by 1993-1994, and further advanced into Qassim

and Najran by 1998-1999. By 2015, RPW had reached Jawf and Asir, and by 2022, it had further spread to Jazan, establishing a presence in 12 of the Kingdom’s 13 regions.

1.4.2. RPW Behavior

The life cycle of RPW makes control efforts more difficult. The weevil undergoes four stages: egg, larva, pupa, and adult. These stages are illustrated below in Figure 1 from the MEWA and WEQAA Center RPW Manual 2022 and are described in Table 1 as follows:

Figure 1: RPW Life Cycle Stages

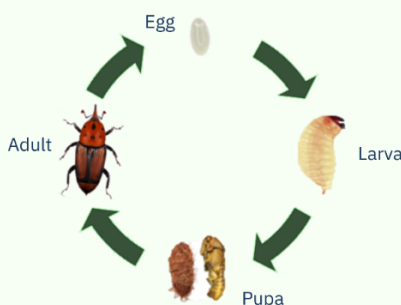


Table 1: RPW Life Cycle Stages

RPW Lifecycle Stage	Description
Egg	Cylindrical, creamy-white, smooth, and measures about 2.5 mm in length and 0.5 mm in width.
Larva	White to yellowish with a distinct red head and no legs. It can grow up to 5 cm long and 2 cm wide.
Pupa	Enclosed in a fibrous, cocoon-like structure within the tree. Initially creamy-white, it turns reddish-brown as it matures, growing up to 3.5 cm in length and 1.5 cm in width.
Adult	The adult RPW has a reddish-brown body with dark spots and measures 3.5 cm. It can live for 2-3 months, starting the infestation cycle again.

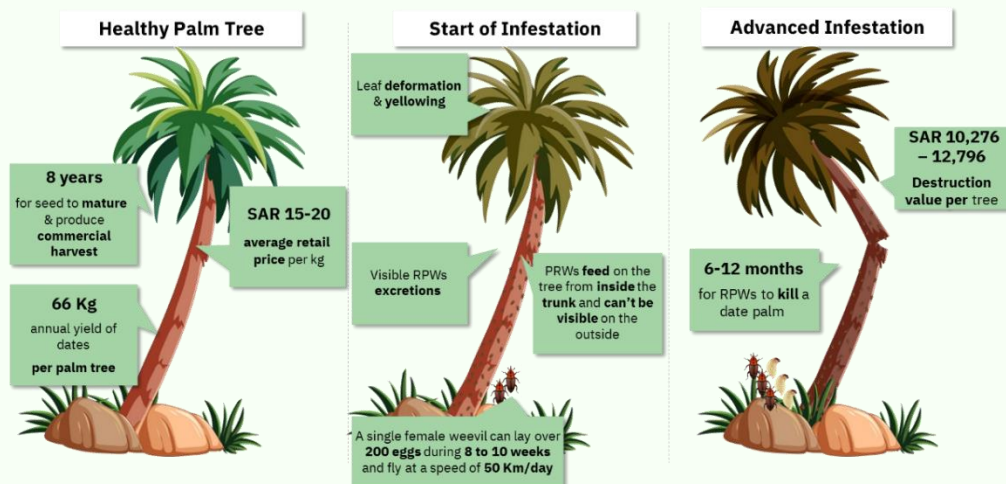
The RPW's elusive behaviour makes early detection challenging. The infestation begins when the weevil hides itself inside the tree and deposits its eggs. The infestation stages of a palm tree can be summarized as follows:

1. **Healthy Palm Tree:** The tree is thriving, with an annual date yield of 66 kg.
2. **Start of Infestation:** Early signs include leaf deformation and yellowing, along with visible RPW excretions. After the eggs hatch, the larvae burrow inside the tree, creating cavities that prevent water transmission from the roots to the crown, causing water stress and heating of the tree.
3. **Advanced Infestation:** RPW can kill a palm tree within 6-12 months starting when the first eggs are deposited, leading to substantial economic losses.

At an average market price of SAR 15-20 per kg, the destruction value per tree is estimated at SAR 10,000-12,250, calculated by quantifying the production loss, operating cost, and removal & planting cost of the palm tree.

Figure 2 below illustrates the stages of RPW infestation on a palm tree.

Figure 2: Palm Tree RPW Infestation Stages



Source: Developed based on data from International Center for Agriculture and Biological Sciences, Allmha Landscaping and General Contracting, Date Palm Research Center of Excellence at King Faisal University (KFU), and NCPD

1.4.3. RPW Importance of Early Detection

Effective early detection is crucial for accurately determining the infestation stage of a palm farm. In the past couple of decades, detection has been primarily done by human detection. However, the challenge of detection is compounded by the lack of external RPW infestation symptoms, making it difficult for untrained personnel to identify the infestation. Effectively detecting RPW infestations demands substantial trained manpower and considerable time, particularly when monitoring a large number of trees across vast areas, leading to high detection costs. The below visual illustration represents an RPW infestation from an external and internal view, highlighting the difficulty of detecting the insect from the exterior. Note that the green arrow shown points to a visible area on the palm tree's exterior where an RPW infestation has occurred.

Figure 3: RPW Infestation Illustration



Source: The RPW Manual 2022 by MEWA and WEQAA Center

The challenges associated with the cost and resources required for early detection are significantly greater for larger farms than smaller ones, as they demand considerably more personnel, training, and time for effective monitoring and detection. This disparity is evident in the data: while smaller farms have achieved a notable reduction in infestation rates from 0.98% in 2016 to 0.26% in 2023, larger farms have maintained an infestation rate of approximately 2% during the same period, as highlighted in the WEQAA Center 2023 Annual Report. The progress on smaller farms can be attributed to targeted efforts, such as WEQAA Center's close monitoring of farms with fewer than 500 trees and its farmer training programs aimed at managing infestations effectively.

To further enhance RPW management, raising awareness about good agricultural practices—spanning detection, monitoring, treatment, and other critical RPW management measures—is essential. Complementing these efforts, the development and deployment of technologically advanced solutions are crucial to achieving sustainable progress.

2. Opportunities to Further Capitalize on RPW Control

2.1. Existing Practices

Several technologies have been deployed to mitigate RPW infestation, though further advancements are necessary to achieve more comprehensive control. These technologies can be categorized into four key stages of the RPW intervention value chain, alongside the current national practices implemented at each stage:

Table 2: *RPW Intervention Value Chain Stages Definitions and Current National Practices*

Intervention Value Chain Stage	Definition	Current National Practices (not comprehensive)
Prevention	Proactive measures to prevent the introduction and spread of RPW, with an emphasis on preserving tree health.	The practices include planting trees (e.g. quarantine protocols), tree maintenance (e.g. pruning), and managing the surrounding environment (e.g. proper waste disposal).
Detection and Monitoring	Tools and technologies for the early detection of the RPW infestation and monitoring of the health of a palm tree (based on infestation severity).	Conventional tunneling and visual detection methods are commonly used, but they often fail to detect infestations early. Trained dogs, however, offer an accuracy rate of over 80%.
Treatment	Curative measures to control or eradicate RPW.	The current approach involves manually removing the weevils from the palm tree, alongside the application of chemical pesticides.
Revival or Removal	Efforts to restore damaged trees or safely remove	Severely infested trees are removed and disposed of through shredding and burial,

Intervention Value Chain Stage	Definition	Current National Practices (not comprehensive)
	those that are beyond recovery.	while partially damaged trees can be revived using traditional fertilizers.

The effective management of RPW infestation is driven by important interventions and operations carried out by the Kingdom. These initiatives encompass managing, controlling, and reporting the infestation, and creating a comprehensive strategy for RPW management.

To properly manage the infestation, as of 2023, WEQAA Center has dedicated a workforce of around 2,000 employees responsible for overseeing RPW control, to conduct inspections and treatments of palm trees. As for controlling the infestation, WEQAA Center has conducted more than 74 million inspections of palm trees and treated over 18,700 trees via scraping and injection techniques. This reduced the infestation rate for farms with fewer than 500 trees to 0.26% according to WEQAA Center 2023 Annual Report. In terms of reporting, WEQAA Center has developed 11 executive plans to monitor the RPW infestation in the country.

2.2. Strategic Framework for Enabling 4IR Transformation in Agriculture and Current Efforts

The integration of Fourth Industrial Revolution (4IR) technologies into Saudi Arabia's agricultural sector, including the date palm sector, presents a significant opportunity for transforming the sector's economic, environmental and sustainability outcomes. By leveraging advanced technologies such as artificial intelligence, Internet of Things (IoT) sensors, drones, and bio-nanotechnology, the sector can achieve substantial improvements.

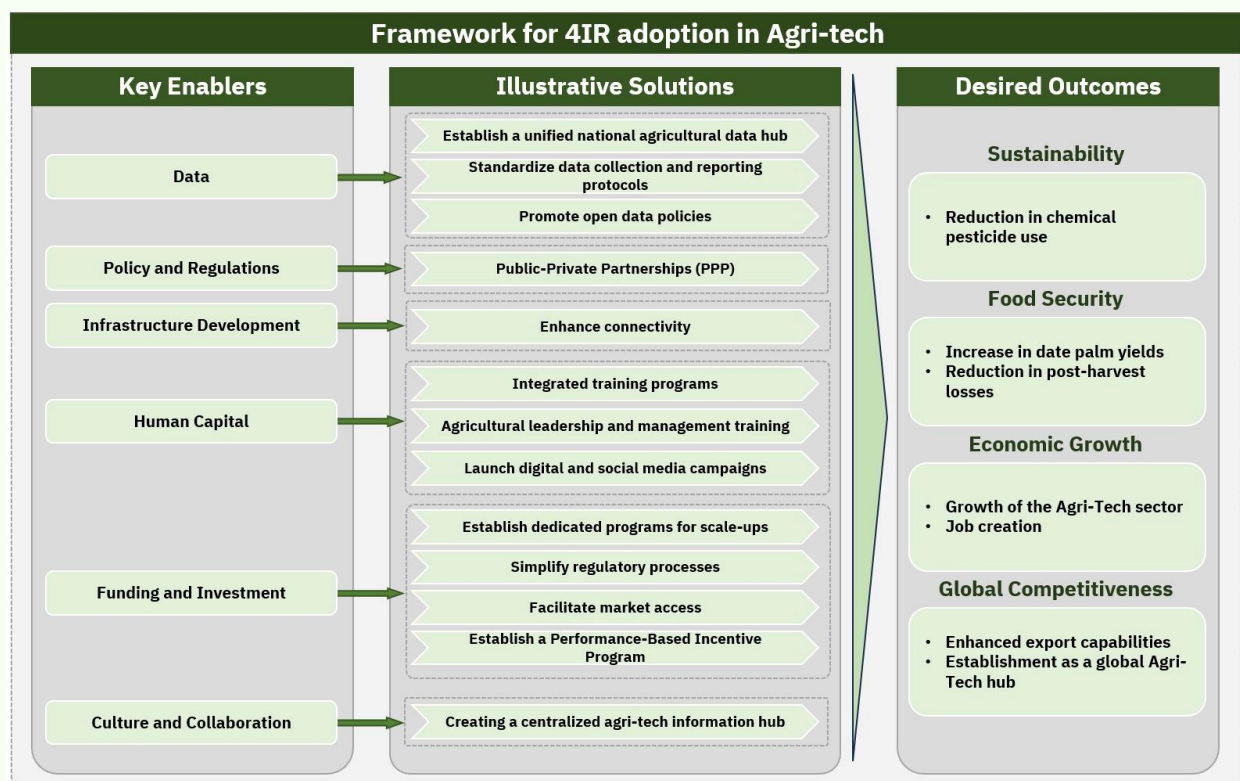
However, the adoption of these technologies in Saudi Arabia faces several challenges. For instance, limited access to capital hampers farmers' ability to invest in new equipment and systems. A shortage of technical expertise makes it difficult to implement and maintain advanced technologies effectively. Additionally, infrastructure gaps, especially in rural areas, impede the widespread deployment of 4IR solutions.

To overcome these obstacles and harness the full potential of 4IR technologies, C4IR KSA has developed a strategic framework for the Saudi Arabian agriculture sector. This framework is built upon six foundational pillars that address key aspects including technological integration,

skill development, infrastructure enhancement, policy support, and ecosystem collaboration. By implementing this multifaceted approach, the framework aims to create an environment conducive to innovation and growth in the agricultural sector, including in the date palm industry.

The framework encompasses a range of recommended interventions and policy support measures. These are designed to facilitate the adoption of 4IR technologies, promote knowledge transfer, and foster a culture of innovation within the agricultural community. Furthermore, the framework aligns with ongoing efforts to develop a thriving agricultural ecosystem in Saudi Arabia. The subject of this report on tech-enabled pest management interventions for red palm weevil can benefit from the broader initiatives in the field, including the framework for 4IR adoption.

Figure 4: Framework for 4IR adoption in Agri-Tech



2.2.1 Key Enabling Pillars for 4IR Adoption

Data

The transformative power of high-quality, well-managed data in agriculture is increasingly known and recognized, driving improvements in productivity, sustainability, and resilience. Data plays a crucial role throughout the entire RPW intervention process, covering prevention detection & monitoring, treatment and revival/removal. A study conducted by McKinsey and the National Association of Software and Service Companies (NASSCOM) in India highlights the significant potential of agricultural data. The research found that utilizing 15 critical datasets, including satellite imagery of farmland, soil health information, and production and consumption data, could generate a \$65 billion opportunity.

Challenges: Saudi Arabia faces several key challenges in managing agricultural data that need to be addressed to support the sector's transformation, including:

- Data fragmentation: collection and managing information by multiple entities.
- Inconsistent methodologies: variations in terminologies and methodologies across datasets.
- Limited open data access: restricted access to data, especially hampering start-ups and researchers.

Addressing these challenges is essential for Saudi Arabia to fully harness the power of data in transforming its agricultural sector, including in managing threats like the Red Palm Weevil.

Illustrative solutions:

- **Establish a unified national agricultural data hub**
Develop a centralized platform integrating crop, soil, water, and pest data to enable real-time, data-driven decision-making.
Example: The European Union's Plant Health Information System consolidates data from member states for rapid and coordinated pest and disease responses.
- **Standardize data collection and reporting protocols**
Adopt harmonized methodologies and formats to ensure consistent, interoperable data across different stakeholders and systems.
Example: The United States Department of Agriculture (USDA) employs standardized data collection for improved management of issues like citrus greening.

- **Promote Open Data Policies**

Encourage secure, anonymized data sharing to foster innovation and collaboration among farmers, startups, and researchers.

Example: Australia's open data initiatives have led to proactive pest detection and monitoring tools by Agri-Tech startups.

Current efforts: Saudi Arabia has made significant progress in using data to fight RPW infestations, primarily through the Nama platform. This electronic service acts as a central hub for RPW-related data, handling both reporting and intervention information. In 2023, Nama processed an impressive 648,400 RPW-related reports, demonstrating its effectiveness and widespread use. The Nama platform has proven particularly useful for smaller farms with fewer than 500 trees. However, to achieve comprehensive coverage across the entire date palm sector, there is a need to expand its capabilities to accommodate larger farms as well. Governance efforts by the National Data Management Office (linked to the Saudi Data & AI Authority) play a crucial role in standardizing data management practices and safeguarding farmer data.

Policies and regulations

The introduction of transformative technologies and practices necessitate a significant evolution in the regulatory landscape to both facilitate innovation and ensure appropriate oversight.

Challenges: The challenges around policies and regulations relate to a need for ensuring that regulations remain up-to-date with the emergence of novel agricultural technologies and practices. In the agricultural sector, this manifests through the introduction of new regulations, updating existing regulations, as required, and enforcement of regulations.

Illustrative solutions:

- **Public-Private Partnerships**

Foster collaborative funding and risk-sharing models between the public and private sectors to accelerate the deployment of IoT networks, digital tools, and precision farming technologies.

Example: India's partnership with IBM on the 'Digital Agriculture' pilot has demonstrated how AI-driven forecasts and soil analytics can significantly improve crop management.

Current efforts: Implemented as part of a strong regulatory framework that includes agricultural regulations and executive laws to curb the spread of RPW. As such, the following are relevant actions taken to control RPW infestation:

- Implementation of internal quarantine protocols to prevent the spread of infection to healthy trees.
- Enforcement of penalties for quarantine violations.
- Establishment of three agricultural quarantine centers.
- Authorization of WEQAA Center by MEWA to appoint 105 plant health control officers across the Kingdom.
- Regulation of 4IR technologies, including permits for drones used in pest spraying, to ensure safe and controlled operations.

While the introduction of regulations strengthens pest management efforts, ensuring compliance from all farmers remains a challenge, highlighting the need to enhance regulatory adherence for long-term RPW control.

Infrastructure development

The introduction and expansion of 4IR technologies in agriculture relies on the availability of adequate physical and digital infrastructure.

Challenges: The adoption of 4IR technologies for pest and disease management in Saudi Arabia's agricultural sector faces two significant infrastructure challenges:

- **Limited Rural Internet Connectivity:** many farms in remote regions of Saudi Arabia struggle with unreliable network access, hindering the full utilization of digital agricultural technologies

Illustrative solutions:

- **Enhance connectivity**
Invest in reliable internet coverage in rural areas to support real-time data transmission and advanced farming applications.
Example: India's telecom partnerships enable IBM's digital agriculture services to reach remote farming communities with critical weather and soil insights.

Current efforts: Saudi Arabia has implemented a comprehensive approach to combat RPW infestations and enhance agricultural productivity. At the core of this effort is the NTP, which provides essential infrastructure to mitigate RPW infestations and reduce economic losses in the agricultural sector. Building on this foundation, MEWA developed the National Strategy for Agriculture, setting an ambitious goal to reduce RPW infestation rates to just 0.1% by 2030.

This strategy is supported by WEQAA Center, which offers the necessary financial and administrative framework to achieve these targets.

On a regional level, programs in Riyadh, Al Madinah, and Al Ula are actively working to address the RPW problem. These initiatives focus on thorough inspection of date palm trees, treatment of infested specimens, and removal of severely affected trees. While these programs have proven effective for smaller farms, they require adaptation to meet the needs of larger agricultural operations.

Complementing these national efforts, the Food and Agriculture Organization has established an RPW eradication program aimed at strengthening pest management practices across the Near East and North Africa region. This international support further bolsters Saudi Arabia's comprehensive strategy to protect its vital date palm industry and improve overall agricultural productivity. As these initiatives continue to evolve, they will play a crucial role in safeguarding Saudi Arabia's agricultural sector against the threat of RPW infestations.

Human capital

The introduction of 4IR technologies represents a profound transformation for the agricultural sector in terms of skill requirements, mirroring trends seen across various industries. As technology becomes an integral part of farming, the adoption of Agri-Tech solutions has shifted from being optional to being essential. This change demands a new level of expertise among farmers, with tasks such as farm data management, advanced machine operation, and statistical analysis becoming crucial for running a successful farm.

To address this evolving technological landscape, initiatives are necessary to empower farm owners and workers. The focus must shift towards equipping the workforce with the technical proficiency needed to embrace modern agricultural practices and technologies.

This transformation in required skills also presents an opportunity to make the agricultural industry a more desirable career choice for younger generations. By emphasizing technological expertise and innovation, agriculture can attract a new wave of talent, ensuring the sector's continued growth and adaptation to future challenges. This aspect is crucial and should not be overlooked, as it has the potential to revitalize the industry and secure its future in an increasingly tech-driven world.

Challenges: The primary challenges related to human capital stem from two interconnected issues. The first is that reliance on unskilled labor where the current agricultural model heavily depends on labor-intensive practices and relatively unskilled workers. The second is that the sector's economic structure often fails to adequately reflect the value of skilled agricultural workers. Challenges include:

- **Resistance to Change:** Farmers often distrust new technologies due to reliance on traditional methods and doubts about their reliability. Many perceive these innovations as complex or unnecessary. This skepticism slows adoption despite potential benefits.
- **Limited Access to Reliable Information:** Farmers can struggle to have access to accurate, centralized information about Agri-Tech.

Illustrative solutions:

- **Integrated training programs**
Combine traditional agricultural practices with hands-on instruction in IoT, drones, and precision farming, weaving them directly into daily farm routines. Training programs should include on-farm demonstrations where possible.
Example: The “Smart Farms” initiative in the Netherlands offers blended on-site and virtual sessions to enhance resource use and increase yields.
- **Agricultural leadership and management training**
Develop programs on project management, innovation, and strategic planning to prepare a new generation of forward-thinking farm leaders.
Example: Australia’s “AgriLeaders” program equips emerging leaders with financial, managerial, and sustainability expertise to drive sector-wide growth.
- **Launch digital and social media campaigns**
Leverage videos, infographics, and case studies to educate farmers on the advantages of modern technologies and build trust through success stories.
Example: The “Shamba Shape Up” TV show in Africa demonstrates practical agricultural solutions to small-scale farmers, promoting new methods and tools.

Current efforts: Human capital development initiatives are critical to advancing RPW management, with WEQAA Center leading the way through extensive training programs. According to the WEQAA Center 2023 Annual Report, over 5,000 training courses have been conducted, benefiting more than 12,500 participants. These workshops focus on equipping stakeholders with knowledge of emerging technologies and evidence-based strategies. Furthermore, collaborative research teams, including those from KFU and King Saud University (KSU), are advancing the scientific understanding of RPW.

Funding and investments

Transitioning to a future in which 4IR plays a larger role in agriculture requires investment of many resources – financial and non-financial. Funding and investments are needed at various parts of the agricultural sector, including for farmers and for start-ups and researchers developing novel and innovative Agri-Tech solutions.

Many small and medium-sized farmers in Saudi Arabia operate on tight margins and rely on manual labor, making it difficult to invest in modern agricultural technologies. Additionally, access to affordable financing and targeted support mechanisms remains limited, hindering the adoption of innovative practices. While the government has taken steps to address these issues, further efforts are needed to promote inclusivity and ensure a sustainable future for the sector.

Challenges: To foster a robust Agri-Tech ecosystem in Saudi Arabia, several key areas require attention:

- **Supporting scale-ups:** Insufficient resources and guidance available for startups transitioning from early-stage to growth-stage companies.
- **Enabling easier market access:** Creating additional pathways for startups to connect with potential customers and partners in the agricultural sector.
- **Creating mechanisms for testing technologies:** Insufficient facilities or programs that allow startups to pilot and validate their technologies in real-world agricultural settings.

Illustrative solutions:

- **Establish dedicated programs for scale-ups**
Develop specialized funding, mentorship, and international collaboration mechanisms for mature startups looking to expand.
Example: The European Institute of Innovation and Technology (EIT) Food runs scale-up programs offering targeted assistance to accelerate growth and market reach.
- **Simplify regulatory processes**
Introduce clear guidelines and regulatory sandboxes, allowing startups to test and refine their innovations in controlled environments.
Example: Singapore's regulatory sandbox framework supports Agri-Tech experimentation and commercialization under government oversight.
- **Facilitate market access**
Create marketplaces and direct communication channels, connecting scale-ups with agricultural businesses for technology adoption.
Example: India's "AgriBazaar" bridges farmers, tech providers, and buyers, simplifying procurement and fostering efficient transactions.
- **Establish a performance-based incentive program**
Reward farmers for adopting technologies that yield measurable improvements in productivity, sustainability, or resource efficiency.

Example: In the United States, the Conservation Stewardship Program (CSP) offers payments to producers who enhance environmental practices like soil health and water conservation.

Current efforts: MEWA has initiated several programs to boost entrepreneurship across various sectors. A key initiative is the Sunbolah program, which focuses on nurturing an entrepreneurial ecosystem of innovators and investors in the agriculture and food sectors. These efforts aim to support Agri-Tech start-ups developing tailored solutions that leverage 4IR technologies such as the IoT and Artificial Intelligence. These technologies are being applied to address critical agricultural challenges, including pest control and yield optimization. While the current programs effectively support early-stage start-ups, there is a growing need for a more comprehensive strategy to address the unique requirements of mature start-ups ready to expand their operations and impact.

Culture and collaboration

A sector-level governance structure within agriculture generally and within specific value chains like date palms creates the conditions for a cohesive approach. Sector-level governance and coordination should clearly define the roles and responsibilities of various entities at national and regional levels, combining national policy, operational execution, and regional alignment for comprehensive management across Saudi Arabia.

Challenges: To ensure cultural acceptance of 4IR technologies, several critical challenges must be addressed:

- Overlapping responsibilities among different government entities hamper the alignment of agricultural policy at both national and regional levels.
- Cultural norms and traditional practices can create resistance to change, hindering the adoption of modern governance structures and innovative farming techniques.

Illustrative solutions:

- **Create a centralized Agri-Tech information hub**
Offer a user-friendly platform cataloging available technologies, success stories, and training resources, connecting farmers with expert support.
Example: The U.S. “Farmers.gov” portal consolidates resources for farmers, including those related to technology adoption and implementation.

Current efforts: Culture plays a crucial role in fostering awareness and collaboration among all stakeholders in the fight against RPW in Saudi Arabia. The Kingdom has made significant strides in this area through several key initiatives. The establishment of the Supreme

Committee for Controlling RPW in Qassim demonstrates a focused regional approach to tackling the issue. Additionally, MEWA has created educational content and campaigns to raise awareness about RPW and its control measures. Saudi Arabia has also actively participated in international forums to exchange best practices, showcasing its commitment to global cooperation in pest management. Despite these efforts, challenges remain in achieving comprehensive stakeholder engagement and coordination.

Additionally, the Kingdom of Saudi Arabia has developed an integrated governance framework to tackle RPW effectively, centering on specific roles that support coordinated action. The approach is focused on a custodian role for WEQAA Center, which is responsible for executing on-ground operations, WEQAA Center, which manages field activities, monitors infestations, and enforces preventive measures.

In alignment with this, policy and regulatory oversight is handled by MEWA Agricultural Deputyship, providing national direction for the agricultural sector and guiding EWA policy and strategy for RPW management. MEWA also supports innovation within the sector, advancing R&D efforts through its Research and Innovation Deputyship, which drives technology adoption and collaboration with academic institutions.

Gaps in stakeholder participation persist, with a need for more inclusive involvement from small-scale farmers, researchers, and local communities. Furthermore, coordination between the private and public sectors remains limited, hindering the creation of a unified approach to RPW management.

2.2.2 Desired Outcomes

By implementing this framework, many positive outcomes are anticipated. A number of examples are included below.

Sustainability:

- **Reduction in chemical pesticide use:** Adopting integrated pest management strategies that utilize IoT and drone technologies can decrease reliance on chemical pesticides. The implementation of such technologies is expected to reduce chemical pesticide usage, thereby promoting environmental sustainability.

Food Security:

- **Increase in date palm yields:** Enhancing disease and pest management, along with optimizing nutrient management, can improve crop yields. The adoption of these technologies is anticipated to boost productivity in the date palm sector.
- **Reduction in post-harvest losses:** Utilizing real-time data analytics and supply chain optimization tools can minimize post-harvest losses. These technologies are expected to enhance the efficiency of the supply chain, leading to reduced losses.

Economic Growth:

- **Growth of the Agri-Tech sector:** The investment in 4IR technologies is poised to catalyze growth in the Agri-Tech sector, spurring the emergence of innovative startups and generating new employment opportunities. The expansion of this sector is anticipated to make a significant positive contribution to the national economy.
- **Job creation:** The adoption of advanced technologies in agriculture is poised to create new employment opportunities, especially in rural regions. This technological transformation is expected to drive job growth within the agricultural sector.

Global Competitiveness:

- **Enhanced export capabilities:** The implementation of cutting-edge agricultural technologies is poised to transform Saudi Arabia's farming sector, leading to substantial improvements in productivity and sustainability. These advancements are expected to boost crop yields, minimize waste, and optimize resource utilization, particularly water and energy. By embracing these innovative technologies, Saudi Arabia aims to enhance its agricultural output and quality, positioning itself as a more formidable competitor in global agricultural markets. This increased efficiency and productivity are likely to bolster the Kingdom's export potential, allowing it to expand its presence in international trade.
- **Establishment as a global Agri-Tech hub:** By cultivating a thriving ecosystem of agricultural innovation, Saudi Arabia aims to establish itself as a global frontrunner in Agri-Tech development and implementation. This strategic focus on agricultural technology and innovation is expected to significantly boost the Kingdom's international standing and competitiveness.

This strategic framework for integrating 4IR technologies in agriculture serves as a crucial link between policy formulation, practical implementation, and measurable impact. By adopting a comprehensive approach to addressing challenges, Saudi Arabia's agricultural sector will remain future-proof, robust and innovative.

2.3. Innovation Opportunities

While significant progress has been made in controlling the RPW infestation, further advancements remain essential to sustain and enhance efforts. The ongoing reliance on manual operations highlights the need for more advanced technological solutions. Embracing innovation can help the Kingdom reduce labour-intensive practices and enhance the efficiency of its RPW control methods.

As such, a collaborative initiative, known as the RPW Infestation Solutions Project, has been launched to address the challenges posed by RPW infestations in Saudi Arabia. This project brings together key stakeholders from various sectors including MEWA, C4IR Saudi Arabia, NCPD, WEQAA Center, KFU, KSU, King Abdullah University of Science and Technology (KAUST), and other relevant organizations to combine their expertise and resources in tackling this critical issue. This project aims to develop and implement integrated technological solutions to address the technological gap and effectively control RPW infestations throughout the Kingdom of Saudi Arabia. By leveraging advanced technologies, the project seeks to protect and save infected date palm trees, ultimately contributing to the strengthening of the national economy. However, further improvements are needed to mitigate and suppress RPW populations. Therefore, additional initiatives have been undertaken with the following objectives in mind:

1. **Reduce Infestation Levels:** Leveraging advanced technological solutions to further reduce the spread of RPW. That way, the Kingdom can enhance its ability to detect, monitor, and treat the infestation more effectively.
2. **Develop and Implement a Holistic Approach:** A comprehensive strategy covering prevention, detection, treatment, and revival is essential. Addressing all stages of the RPW lifecycle reduces infestation risks and safeguards the agricultural sector.

3. RPW Infestation Solutions Project

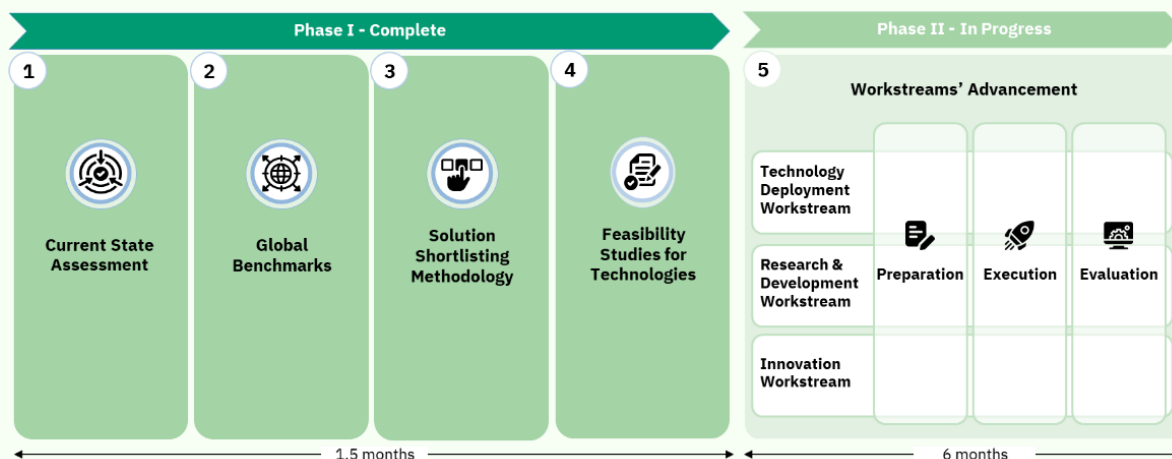
3.1. Purpose and Approach

The RPW Infestation Solutions Project **aims to leverage advanced technological solutions for the effective management of the RPW** in Saudi Arabia. By assessing and using cutting-edge technologies, the project focuses on protecting natural resources and supporting sustainable agriculture, aligning with the Kingdom's broader strategic goals of sustainability and innovation.

The project is structured into two key phases. The first phase involved assessing national efforts to control RPW, identifying gaps, and learning from successful, relevant, global, and pest-related programs in countries like the USA, UK, and Italy. This phase also involved the compilation of a list of potential technologies and conducting feasibility studies to shortlist the most promising solutions for implementation (see Sections [3.2](#), and [3.3](#) for the detailed assessment and [Section 4.3](#) for the benchmarking analysis).

The second phase focuses on planning, deploying, and evaluating these technologies to ensure they achieve the desired impact. The preparation process lays the groundwork for the effective execution and evaluation of the project. By adopting this structured approach, the project emphasizes continuous improvement and the use of innovative technologies to address the RPW challenge effectively across the Kingdom.

Figure 5: Project Approach



3.2. Technology Compilation and Categorization

The baseline analysis and benchmarking identified a long list of RPW control technologies. This process involved reviewing over 420 studies, 90 patents, and 80 AgTech startups, alongside consultations with experts and stakeholders. The 65 technologies identified in the process were categorized into 18 technology categories. They were then grouped based on the RPW intervention value chain, and Technology Readiness Levels (TRL).

Technology Families

MEWA identified a long list of agricultural technology families, six of which were leveraged in classifying the 18 technology categories. These families were extracted from the March 2024 Phase 2: Technology Deployment Roadmap Report. The relevant technology families are identified as follows:

- **Conventional Crop Protection Chemicals:** Target and control the RPW infestation by directly applying chemicals.
- **Agricultural Biotechnology and Crop Improvement:** Focus on genetic manipulation, advanced breeding techniques, and diagnostics to develop RPW-resistant palm varieties and enhance crop health.
- **Innovative Crop Protection:** Use cutting-edge, often non-chemical methods to protect crops from RPW. These solutions either disrupt the pest's lifecycle through innovative methods or detect RPW using advanced sensors.
- **Drones and satellites:** Use aerial technology for large-scale monitoring and detection of RPW infestations, providing real-time data and imagery to inform pest control decisions.
- **Fertilizers:** Enhance soil and plant health to make palm trees more resilient to RPW. It particularly includes fertilizers that improve nutrient delivery, especially after revival from late-stage infestation.
- **Irrigation and water management:** Optimize water use to maintain healthy palm trees, preventing conditions that could attract RPW.

RPW Intervention Value Chain

The RPW intervention value chain is essential for developing an integrated solution to control RPW infestations. As such, the technology categories are classified based on the stage the technology is applied: prevention, detection and monitoring, treatment, and revival or removal, with some falling under more than one value chain stage.

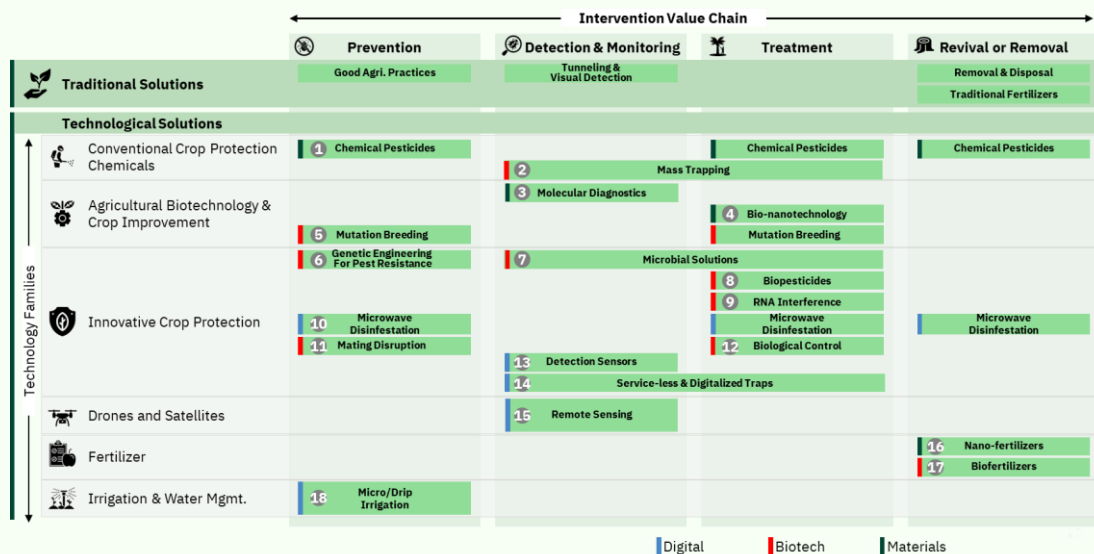
Technology Readiness Levels

The identified technologies have been categorized by their maturity and readiness for deployment. These levels range from:

- **TRL 1-3:** Early-stage, focusing on research with limited immediate practical use.
- **TRL 4-6:** Validated, but still require refinement prior to large-scale deployment.
- **TRL 7-9+:** Fully developed, tested, and ready for broad implementation.

Figure 6 below identifies the 18 RPW control technology categories after classification according to the RPW intervention value chain stage and their respective technology families. Table 3 below presents the long list of 65¹ technologies within 18 technology categories.

Figure 6: Technology Categories Across RPW Intervention Value Chain Stages



¹ Some of the technologies address more than 1 stage of the value chain

Table 3: Technology Categories with Respective Technologies

#	Technology Family	Technology Category	Technologies
1	Conventional Crop Protection Chemicals	Chemical Pesticides	• Emamectin benzoate • Thiamethoxam • Imidacloprid • Attract and kill • Chitin synthesis inhibitor
2		Mass Trapping	• Mass trapping
3	Agricultural Biotechnology & Crop Improvement	Molecular Diagnostics	• RferOR1 pheromone receptor • DNA barcoding
4		Bio-nanotechnology	• Nanochitosan • Nanoparticles
5		Mutation Breeding	• Precision-guided sterile insect technique • Incompatible insect technique protocol
6	Innovative Crop Protection	Genetic Engineering for Pest Resistance	• Intrinsic mechanisms of plant resistance to insects
7		Microbial Solutions	• Genetically engineered Escherichia coli strains • Entomopathogenic nematodes (H. bacteriophora)

#	Technology Family	Technology Category	Technologies
			- Entomopathogenic nematodes (S. carpocapsae) - Entomopathogenic nematodes (S. feltiae) - Entomopathogenic nematodes (S. glaseri) - Entomopathogenic fungus JEF-158 - Entomopathogenic fungus JEF-484 - Beauveria bassiana B. thuringiensis - Fungi: Metarhizium anisopliae - Fungi: Lecanicillium lecanii - Bacteria: gut microbiota - Bacteria: Serratia marcescens - Predators: mites
8		Biopesticides	- Chitinase from Beauveria bassiana - Petroleum ether extract of Justicia brandegeana - Serene protease inhibitors - Sesquiterpenes picrotoxin - Biotech: genome-based - Biopesticides: essential oils - Azadirachtin

#	Technology Family	Technology Category	Technologies
9		RNA Interference	• Vitellogenin based dsRNA feeding • α-amylase dsRNA delivery • RferOR1-silencing
10		Microwave Disinfestation	• Eco palm ring and box
11		Mating Disruption	• Pheromone mating disruption
12		Biological Control	• Billaea rhynchophorae
13		Detection Sensors	• LiDAR • Acoustic sensor • Thermal sensor • X-ray • Radar • Resistograph • Near-infrared spectroscopy • Seismic sensors • Densitometer • Accelerometer • Photonic sensor
14		Service-less and Digitalized Traps	• Service-less and digitalized traps

#	Technology Family	Technology Category	Technologies
15	Drones and Sensors	Remote Sensing	• Drones with sensors • Satellite image analysis
16	Fertilizer	Nano-Fertilizer	• Seaweed extract
17		Biofertilizer	• Biofertilizer (compost, MycENA16 and PA strain)
18	Irrigation & Water Management	Micro/Drip Irrigation	• Micro/drip irrigation

3.3. Technology Detailing and Scoring

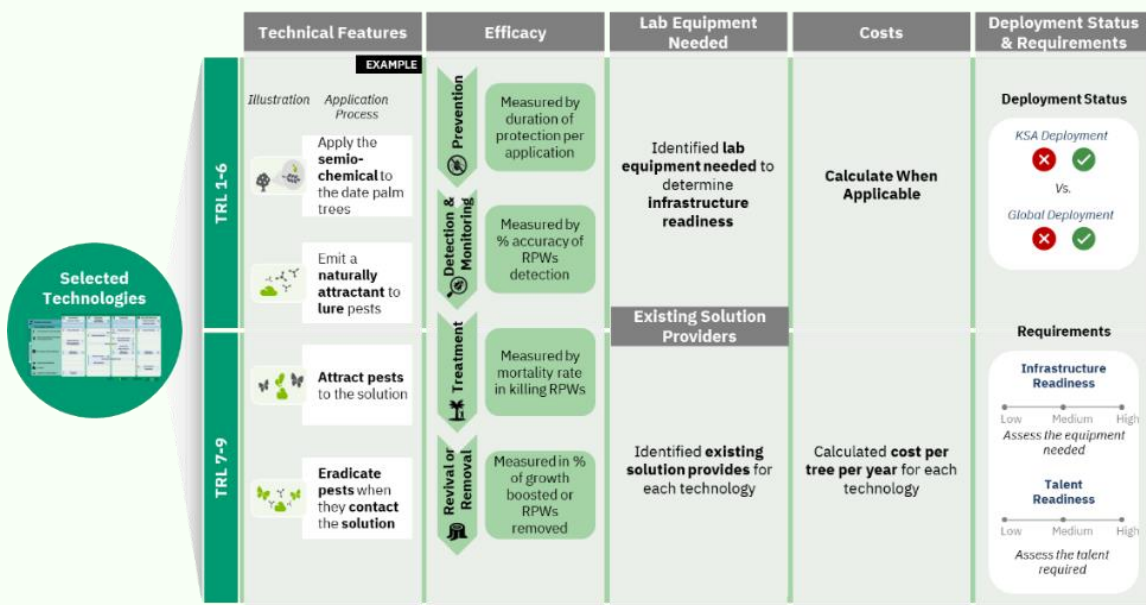
The next step involves a detailed assessment and scoring process. Each technology was thoroughly evaluated based on several critical dimensions identified below to ensure its suitability and effectiveness within the context of KSA:

- **Technical features:** The technical features of each technology were analyzed, focusing on its application process. For example, some technologies involved applying attractants directly to the trees, while others used naturally occurring attractants to lure the weevils. These technical features were essential in determining the overall efficacy of the technology based on the specific stage of the RPW intervention value chain to which it pertains.
- **Efficacy:** The efficacy of each technology was evaluated according to the specific RPW intervention value chain stage it addresses, with tailored metrics for each stage. Prevention was evaluated using the duration of protection per application, detection, and monitoring measured using the percentage accuracy of RPW detection, treatment measured using the mortality rate of RPWs, and revival or removal based on the percentage of growth boosted or RPW removed, respectively.

- **Lab equipment:** Determining lab equipment requirements for TRLs 1-6 and suitable existing solution providers for TRLs 7-9+
- **Costs:** The costs for each technology were calculated, including the installation and unit costs for TRL 1-6 technologies and on a per-tree-basis for TRLs 7-9+ technologies.
- **Deployment status:** The deployment status and requirements were assessed, including indicating whether the technology is deployed in KSA and if it is also adopted globally, while also considering the level of infrastructure and talent readiness for successful implementation.

As shown in Figure 7 below, technologies were scored and prioritized based on two key factors: impact and ease of experimentation/deployment. Impact was evaluated through effectiveness (protection duration and detection/treatment efficacy) and environmental impact (effect on the ecosystem). Ease of experimentation/deployment was assessed through talent readiness, infrastructure readiness, and financial feasibility. Each criterion was rated from zero to four with equal weight, ensuring a balanced and thorough evaluation, leading to the shortlisting of the most viable and sustainable technologies.

Figure 7: Technology Detailing



The prioritization process involved collaboration with 11 national and international experts from institutions like WEQAA Center, NCPD, and KACST, who helped evaluate 65 technologies. Of these, 32 were in TRLs 7-9+ (ready for deployment), while 33 were in TRLs 1-6 (needing

further research and development). Conducted in two phases, the near-identical results across both phases demonstrated the robustness and consensus of the evaluation process.

Figure 8: Technology Scoring Methodology

		0	1	2	3	4
Impact	Effectiveness	Normalized to 0-4 for each value chain element based on measurement of duration of protection, accuracy in detection, efficacy in mortality rate, or effectiveness in boosting growth				
	Environmental Impact	Direct negative impact exists		No direct negative impact, but indirect impact might exist		No direct or indirect environmental impact
Ease of Experimentation or Deployment	Talent Readiness	World-class expertise required for implementation	PhD level of expertise is required	Some training is required	Some instruction is required	Almost no training or instruction required for implementation
	Infrastructure Readiness	Impossible to implement given the existing regulation	New equipment or system needed, and heavy regulatory restriction are present	New equipment or system needed, regulatory restriction are present but meetable	New equipment or system needed, but can be easily purchased or set up	Existing infrastructure is enough for implementation
	Financial Feasibility*	Normalized to 0-4 for each value chain element based on cost per tree per year				

*Only applicable to technologies with TRL level > 6

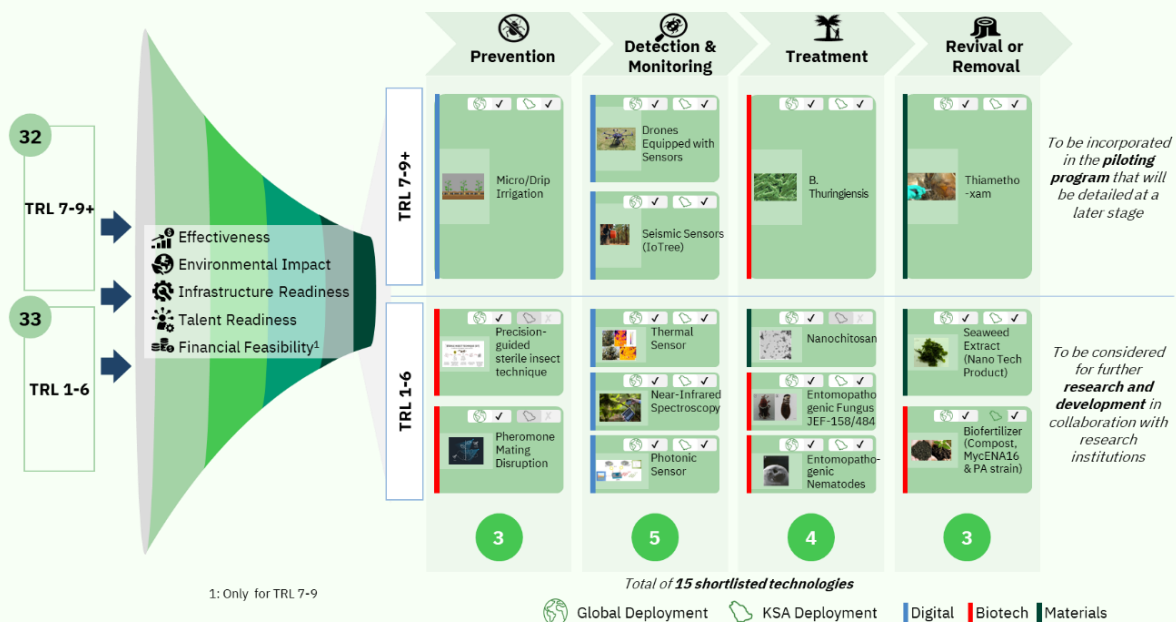
4. Key Findings and Outputs

4.1. Shortlisted Technologies

After completing the prioritization process, 15 shortlisted technologies were identified as the most suitable for controlling the RPW infestation across the RPW intervention value chain. Within TRLs 1-6, 5 technologies were identified to be implemented through a research and development program.

An additional 10 technologies within TRLs 7-9+ were shortlisted and will be implemented through a technology deployment program for piloting. These include more mature technologies that span the entire RPW intervention value chain. The following figure captures the journey of the technologies from the initial 65 technologies inclusion in the initial long list, to their evaluation based on the five main criteria, culminating in their shortlisting along the RPW intervention value chain.

Figure 9: Prioritized Technologies Across RPW Intervention Value Chain Stages



4.2. Project Workstreams

Four main workstreams were developed to advance the implementation of shortlisted technologies: Research and Development, Technology Deployment, Commercial Deployment, and Systemic Enablement.

Workstream #1 – Research and Development: This workstream’s objective is to advance the 10 early-stage shortlisted technologies (TRLs 1-6) through a research and development program. The goal is to advance promising technologies in collaboration with academic institutions, industry players, and research organizations. Seven main research topics were identified from the 10 shortlisted technologies: Male sterilization, mating disruption, early detection sensors, nanotechnology, biotechnologies (biological control), biofertilizers, and plant extract. Research on these topics will be conducted through three research consortia and four research themes. This collaborative approach not only advances technological solutions, but also enhances the Kingdom’s credibility in the field of innovation.

Workstream #2 – Technology Deployment: This workstream focuses on scaling and implementing the 10 mature shortlisted technologies (TRLs 7-9+) through the innovation deployment program (IDP). The objective is to transform the sector by deploying these technologies on a wide scale. Depending on their readiness, these technologies are either tested through pilot programs or, if proven effective, deployed on a nationwide scale. The IDP aims to validate the technical efficacy of the technologies under real-world conditions, while also assessing cost efficiency, scalability, and environmental impact. This ensures that only the most promising solutions are rolled out countrywide.

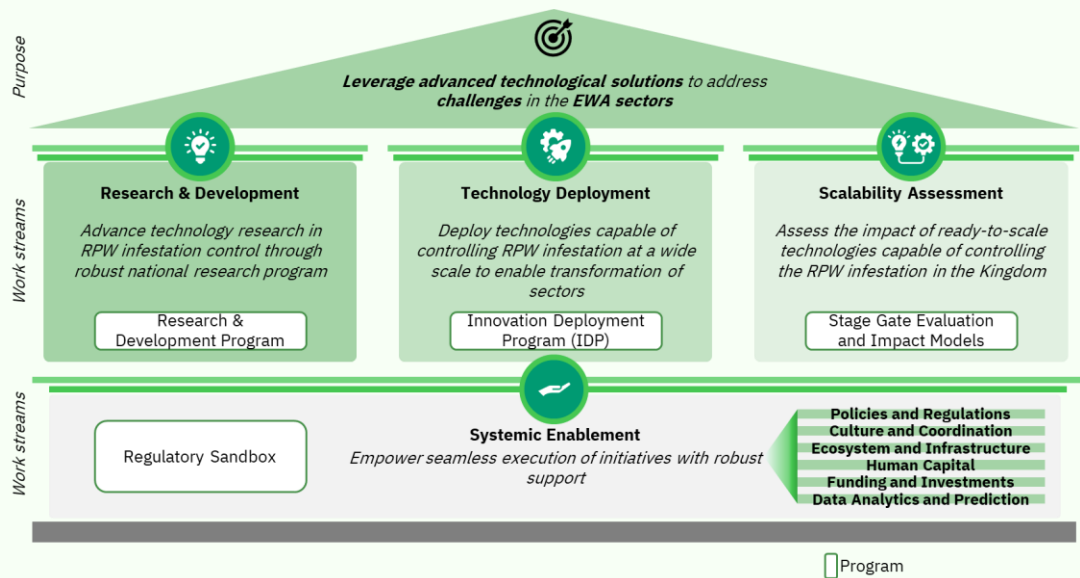
Workstream #3 – Commercial Deployment: This workstream is dedicated to enabling the successful scaling and integration of RPW control technologies by focusing on key enablers: regulatory support, infrastructure platforms, coordination mechanisms, capacity building, and data-driven insights. Regulatory support ensures the establishment of policies and permits to facilitate the seamless adoption of advanced technologies. Infrastructure platforms, such as digital tools and service hubs, provide essential support for monitoring and deployment. Coordination mechanisms enhance collaboration among stakeholders to align efforts and optimize resources. Capacity building equips stakeholders with the necessary technical expertise to implement solutions effectively, while data-driven insights, supported by a national database, enable informed decision-making. Together, these enablers create a comprehensive framework for scaling RPW technologies across the Kingdom.

Workstream #4 – Systemic Enablement: This workstream is essential for ensuring the seamless execution and long-term sustainability of the workstreams. It is designed to provide robust foundational support, focusing on a comprehensive range of enablers. These enablers include policies and regulations, culture and coordination, as well as ecosystem and

infrastructure, human capital, funding and investments, and data analytics and prediction. The key program is the Regulatory Sandbox, a controlled environment designed to develop innovative technologies with high potential impact in the EWA sectors. This effort alongside the provision of the enablers ensures that all workstreams are not only effectively implemented, but also positioned for enduring impact.

Figure 10 illustrates the adopted project workstream framework.

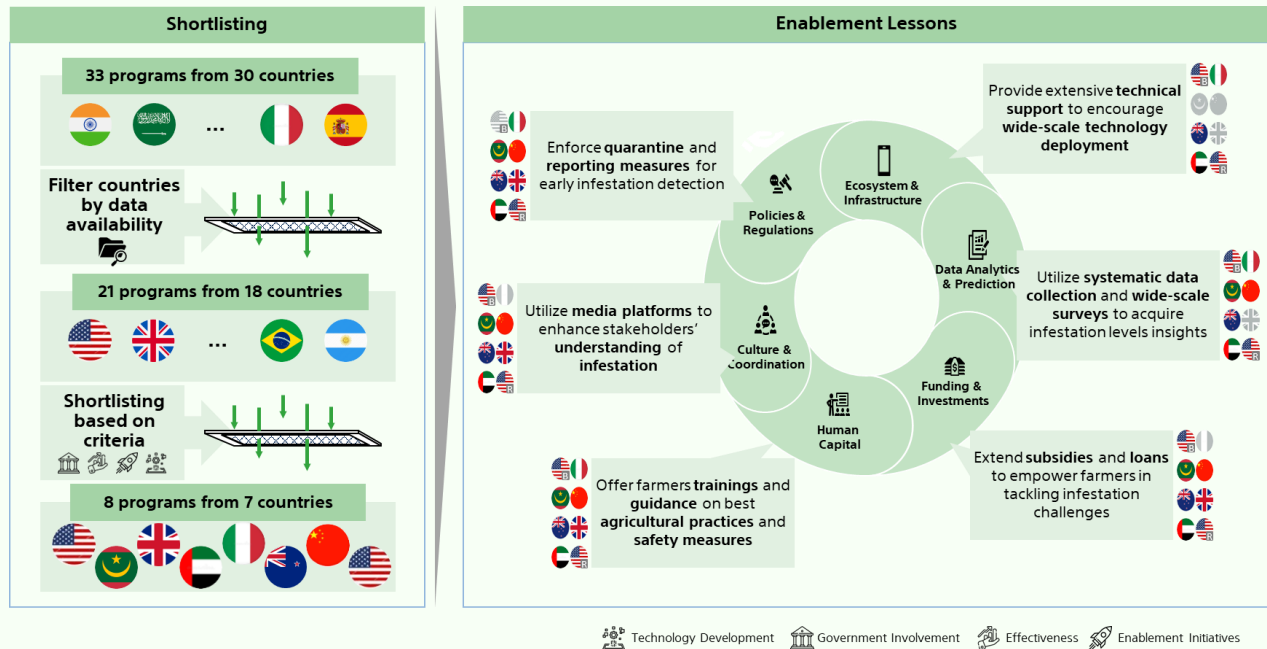
Figure 10: Project Workstream Framework



4.3. Best Practices for Enablers

Given the importance of Systemic Enablement to support the other project workstreams, it is crucial to detail the best practices for each enabler through leveraging global benchmarks. Therefore, 30 countries with significant expertise in RPW management or similar agricultural challenges were selected based on factors such as the number of RPW-related publications, pesticide usage, and date production. Subsequently, 33 programs across the identified countries were evaluated and shortlisted to eight programs from seven countries based on data availability and four key criteria: technology deployment, government involvement, program effectiveness, and coverage of enablement initiatives. After analyzing the eight programs, key insights were identified for each of the six enablers. The following figure represents a summary of the benchmarking approach and key insights for the six enablers:

Figure 11: Enablement Benchmarking Approach and Lessons



4.4. Project Initiatives

After establishing the project workstreams and assessing the best practices for enablers, 14 initiatives were deployed to drive the successful execution of the RPW workstreams. The initiatives are aimed at scaling commercially ready technologies, fostering research development, building a vibrant innovation landscape, and guaranteeing systemic enablement

Table 4: Initiatives of the Project Workstreams

#	Workstream	Reference	Initiative
1	Research & Development	1.1	Establish three research consortia to advance and test technologies in early TRL stages.
		1.2	Develop a partnership plan to launch open calls for proposals for technologies with potential to control the RPW infestation.
2	Technology Deployment	2.1	Deploy shortlisted technologies as part of a pilot program.

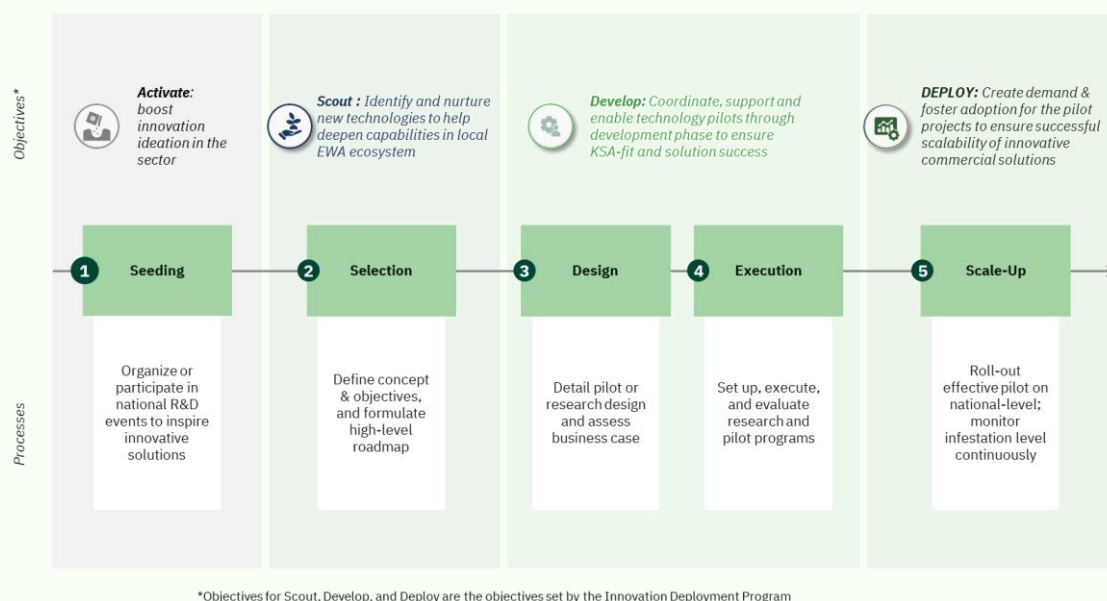
#	Workstream	Reference	Initiative
3	Commercial Deployment	3.1	Identify essential resources required to support and scale RPW control technologies effectively.
		3.2	Implement tailored support measures for each RPW control technology, ensuring successful deployment.
4	Systemic Enablement	4.1	Secure permits and licenses required for the adoption of the identified innovation technologies.
		4.2	Leverage existing channels relevant to RPW, agriculture, or innovation to promote the use of innovative technologies in controlling RPW.
		4.3	Empower existing training programs with specific expert support and knowledge materials to integrate the use of innovative technologies into RPW control measures.
		4.4	Integrate technology support services into existing RPW platforms.
		4.5	Secure grants and funding for the research and deployment of technological solutions.
		4.6	Create and maintain a national database that tracks real-time infestation data across the Kingdom, identifying high-risk areas to enable data-driven decision-making.

4.5. Operating Model

To properly execute the RPW Infestation Solution Project, a robust operating model was developed. It includes five main processes under four key objectives.

1. **Activate:** This objective begins with the seeding process to stimulate innovative solution development through national R&D events. (~140 days).
2. **Scout:** The selection process under this objective identifies and supports new technologies, ensuring they deepen capabilities within local EWA ecosystems. (~45 days).
3. **Develop:** This includes the design and execution processes, focusing on the adaptation and success of technology pilots to meet KSA-specific needs. (~210 days).
4. **Deploy:** The scale-up process aims to create demand and facilitate the adoption of pilot projects, ensuring the technologies can be scaled up successfully. (~140 days).

Figure 12: Process Framework



Seeding, which is the first process, focuses on organizing or participating in national research and development events that inspire the development of innovative solutions. The process is crucial in laying the groundwork for discovering cutting-edge technologies that can address RPW infestation control.

Following seeding, the selection process focuses on defining clear concepts and objectives for each potential solution and formulating a high-level roadmap to guide their development. The selection process ensures that only the most viable and impactful technologies progress and advance.

Once technologies are selected, the design process takes over, detailing the research design or deployment plan needed to assess each technology's business case. The process meticulously plans every aspect of the technology's deployment, setting the stage for successful deployment programs.

The execution process then brings these plans to fruition. It involves setting up, executing, and evaluating the research and deployment programs, ensuring that the technologies are tested in real-world conditions. The insights gained from this stage are vital in refining the solutions and determining their readiness for nationwide scalability.

Finally, the scale-up process ensures that innovative commercial solutions are rolled out effectively at a national level. Continuous monitoring of RPW infestation levels and other key metrics helps maintain the efficacy of the deployed technologies, ensuring they continue to meet the sector's needs over time.

All five processes (under the four objectives) were detailed to ensure their proper execution, with the process owner, duration, internal and external stakeholders, and other key elements specified. With a summary of the processes duration and stakeholder shown below:

Table 5: Key Process Details

Process Name	Process Duration (Approximate)	Internal and External Stakeholders
Seeding	140 days	• Experts • Vendors • Project Operation Team • Project Advisory Board • Project Executive Committee • Project Steering Committee

Process Name	Process Duration (Approximate)	Internal and External Stakeholders
Selection	45 days	• Experts • Project Operation Team • Project Advisory Board • Project Executive Committee • Project Steering Committee
Design	70 days	• Vendors (for Innovation Deployment Program) • Partnership Consortium (for Research & Development Program) • Project Operation Team • Project Advisory Board • Project Executive Committee • Project Steering Committee
Execution	140 days	• Experts • Vendor/Research Institutions • Project Operation Team • Project Advisory Board • Project Executive Committee • Project Steering Committee
Scale-up	140 days	• External Partners • Vendor/Research Institutions

Process Name	Process Duration (Approximate)	Internal and External Stakeholders
		• Project Advisory Board • Project Executive Committee • Project Steering Committee

This comprehensive approach ensures that each process is well-defined and executable, allowing for the technologies' effective transition from innovative ideation to large-scale deployment. The operating model not only addresses the immediate needs of RPW management, but also supports the broader objectives of enhancing the productivity, sustainability, and resilience of the palms and dates industry.

5. Conclusion

In conclusion, Saudi Arabia's date palm sector is rooted deeply in the nation's heritage, with the date palm symbolizing resilience, generosity, and sustenance for thousands of years. As a sacred plant in Islam, the date palm holds historical and religious significance, being mentioned in the Qur'an and praised for its blessings and health benefits in the teachings of the Prophet Muhammad, peace be upon him. This heritage is reflected in the Kingdom's commitment to preserving and advancing the date palm industry, a pillar of its national identity and agricultural economy, and in maintaining its position as one of the world's largest producers of dates.

In response to this commitment, the Kingdom has achieved a reduction in RPW infestation rates from 0.98% in 2016 to 0.26% in 2023 for small farms, though opportunities remain to extend mitigation efforts to larger farms, where infestations are less effectively controlled. This highlights the need for a robust, technology-enabled approach to control RPW more comprehensively across farms of all sizes. In line with Vision 2030, MEWA has joined forces C4IR KSA, NCPD, WEQAA Center, and leading academic institutions to establish an integrated technological solution for nationwide RPW management.

The RPW Infestation Solution Project embodies a holistic approach to identifying and deploying innovative technologies to combat RPW infestations. This led to the development of four main workstreams (Research and Development, Technology Deployment, Commercial Deployment, and Systemic Enablement). Beginning with an in-depth analysis of the Kingdom's palm and date industry, this approach identified that while some RPW solutions are already in place, further technological innovation is required to sustain and enhance these efforts.

Following a rigorous prioritization methodology, relevant RPW control technologies were compiled and shortlisted to ensure alignment with the Kingdom's strategic goals. Supporting these workstreams are systemic enablers that include policies and regulations, infrastructure, data analytics, human capital, and funding mechanisms, all coordinated within a systematic operating model designed to guide the research and deployment of the selected technologies.

With this comprehensive framework in place, the RPW Infestation Solution Project is now prepared to advance to its second phase, which will focus on preparation, execution, and evaluation of the identified workstreams. This phase is crucial for ensuring the effective integration of advanced technologies into the Kingdom's RPW management efforts. Through this initiative, Saudi Arabia stands poised to enhance the sustainability and prosperity of its date palm industry, securing a future where the sector continues to flourish amidst innovation and agricultural resilience.

Acknowledgements

Ministry of Environment Water & Agriculture

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Eng. Ahmed Saleh Aiadh Alkhamshi

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